ED 474 508 SE 067 417

AUTHOR	Hake, Richard R.
TITLE	Is It Finally Time To Implement "Curriculum S"?
SPONS AGENCY	National Science Foundation, Arlington, VA.
PUB DATE	2000-00-00
NOTE	100p.
CONTRACT	DUE-MDR-9253965
AVAILABLE FROM	Web site: http://www.physics.indiana/edu/~hake/ .
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	EDRS Price MF01/PC05 Plus Postage.
DESCRIPTORS	*Curriculum Development; *Educational Change; Elementary Secondary Education; Higher Education; *Physics; *Science Education; *Teacher Education Programs

ABSTRACT

This document describes the need for improved physics education of K-12 teachers and suggests "Curriculum S" as a possible partial solution. "Curriculum S" for synthesis intends to serve students who want to study physics as background for something other than physics research. The document presents some models of "Curriculum S" programs proposed at the Princeton Conference in December, 1963. The need for general reform of P-16 education is also discussed with examples of programs. (KHR)

Is it Finally Time to Implement *Curriculum S*? * ‡

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Walt Kelley's Pogo

"We have met the enemy and he is us". . . .

(University Faculty . . . We have failed to provide a *Curriculum S* ! !)

*Partially supported by NSF Grant DUE/MDR-9253965.

‡ The reference is R.R. Hake, "Is it Finally Time to Implement *Curriculum S*?" *AAPT Announcer* **30**(4), 103 (2000); on the web at < **http://www.physics.indiana.edu/~hake/** >. Note that hot linked URL's are in < **bold blue** >.

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OUTLINE

I. Need for Improved Physics Education of K-12 Teachers

A. TIMSS Results

1. NRC, *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education* (National Academy Press, 1999); < http://www.nap.edu/catalog/9605.html >:

"U.S. students' worst showing was …….. (final year of secondary school……corresponding to U.S. high-school seniors)…….*In the assessment of general mathematics and science knowledge, U.S. high school seniors scored near the bottom of the participating nations.* In the assessments of advanced mathematics and physics given to a subset of students who had studied those topics, no nations had significantly lower mean scores than the United States. *The TIMSS results indicate that a considerably smaller percentage of U.S. students meet high performance standards than do students in other countries*."

2. **M. Neuschatz, "What can the TIMSS teach us?"** *The Science Teacher* **66**(1), 23-26 (1999):

"In the study…..(the 12th grade portion)….. U.S. students tied for last place in physics and scored almost as low in advanced mathematics……..*The explanation ……. may not be that our students are getting so little of the physics they take, but rather that they are taking so little in the first place* ……..the TIMMS study pitted U.S. students against those with twice as much physics study under their belts…….The U.S. still stands out among its industrial partners as exposing a smaller proportion of students to physics in secondary school and encouraging even fewer to attempt a more intensive study of the subject. *The notion put forth by the TIMSS researchers that the syllabi for our courses tend to be 'a mile wide and an inch deep' seem to have a good deal of merit*." (My *italics*.)

3. S. Bowen, "TIMSS - An Analysis of the International High School Physics Test," *APS Forum on Education Newsletter*, Summer 1998, pp. 7-10; **< http://www.research.att.com/~kbl/APS/aug98/TIMSS2.htm >**:

"The major difference mentioned in the reports is that the U.S. curricular materials are '*a mile wide and an inch deep.*' By this is meant that the curricula in the U.S. present many topics, but no subject is covered in any depth and there is very little difference in the emphasis between subjects.

Because the study was able to look at students in both 7th and 8th grades, it was possible to see if there are any gains in subject matter competency between these grades. In several countries, students showed gains in some subjects, mostly those that had been covered in some depth in their schools. *In the U.S., by contrast, no subjects showed a gain in knowledge and skill.*

. .....(in my opinion TIMSS tells us that) . . . we are not generally giving students an understanding of physics which supports generalization and manipulation of concepts in new contexts. . . . . . . *A large fraction of existing high school teachers will soon be retiring; the physics community has a great opportunity.*" (My *italics*.)

4. R.B. Schwartz, "Lessons from TIMSS," *Hands On** **21**(1), 4 (1999):

"If the public debate about the meaning of these results is conducted only between the doomsayers and the 'Don't worry, be happy' crowd, we will all miss an opportunity to benefit from the *important lessons of TIMSS, which are found not in the comparative ranking of the countries but in the extraordinary sub-studies that accompany the administration of the tests…….*

The first study focusing on textbooks, strongly suggests that, *in the absence of clear agreements about what students are supposed to know and be able to do at each grade or cluster of grades, our textbooks err on the side of inclusiveness, treating a large number of topics superficially rather than a handful of topics in depth…….*

The second study examines videotaped classrooms in Germany, Japan, and the U.S., and this is enormously instructive[1] in what it reveals about the focus on pedagogy in the three countries. Simply put, the *American lessons, especially when contrasted with Japanese classrooms, focus much more on procedures and skills, and much less on concepts, deductive reasoning, and understanding.*

Finally, there are detailed case studies of the same three countries…..(showing, for one thing) …….. *that we track much earlier than either Germany or Japan…*"

(My *italics*.)

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*TERC - Technical Education Research Center < **http://www.terc.edu** >.

[1]For an illuminating analysis of TIMSS videotapes see J.W. Stigler & J. Hiebert, *The Teaching Gap* (Free Press, 1999); see also < **http://www.lessonlab.com/teaching-gap/** >.

5. A.T. Leath, "TIMSS Report Provides International Comparisons in 8th-grade Science & Math, *APS News*, February 2001; < **http://www.aps.org/apsnews/ >:**

On December 5, the US Department of Education's National Center for Education Statistics released preliminary results of the TIMSS-Repeat (TIMSS-R) study, conducted in 1999 on eighth-graders. . . . The TIMSS-R data shows that in science, US eighth-graders outperformed their peers in 18 nations. They performed similarly to their peers in 5 nations, and they scored lower in science than students in 14 nations. In math, the TIMSS-R results show that US eighth-graders performed better than their peers in 17 nations and performed similarly to students in 6 nations. Their scores were surpassed by those of students in 14 nations.

The TIMSS-R data also suggests that US eighth-graders performed worse in science and math in 1999 than US fourth-graders (presumably including many of the same students) did in 1995, when compared to a group of 17 nations that participated in the same two assessments. According to acting commissioner of education statistics Gary Phillips, ***"This finding validates the results of the previous 1995 study that after the fourth grade, students in the United States fall behind their international peers as they pass through the school system."***

The report points out some differences in curriculum, teacher preparation, and teaching practices between the US and other countries, but warns that analysis of the data is still preliminary and cautions against assuming unwarranted correlations. ***US eighth-graders are less likely to be taught math or science by a teacher with a major or main area of specialty in math or physics***, respectively, but are as likely as their international peers to be taught science by a teacher with a major or degree in biology, chemistry, or science education. (My *italics*.)

B. Joint Physics Society Statement on the Education of Future Teachers

On the web at < **http://www.aip.org/education/futeach.htm** >.

"The scientific societies listed below* urge the physics community, specifically physical science and engineering departments and their faculty members, to take an active role in improving the pre-service training of K-12 physics/science teachers. Improving teacher training involves building cooperative working relationships between physicists in universities and colleges and the individuals and groups involved in teaching physics to K-12 students. *Strengthening the science education of future teachers addresses the pressing national need for improving K-12 physics education and recognizes that these teachers play a critical education role as the first and often-time last physics teacher for most students.*

While this responsibility can be manifested in many ways, research indicates that effective pre-service education involves hands-on, laboratory-based learning. ***Good science and mathematics education will help create a scientifically literate public, capable of making informed decisions on public policy involving scientific matters. A strong K-12 physics education is also the first step in producing the next generation of researchers, innovators, and technical workers***." (My *italics*.)

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* American Institute of Physics, American Physical Society, American Association of Physics Teachers, American Astronomical Society, Acoustical Society of America, American Association of Physicists in Medicine, American Vacuum Society.

C. FCI Pretest Scores of HS Physics Course Graduates

1. The Normalized Gain <g>

Definition of "Normalized Gain"[2]

Average *normalized* gain <g> for a course as the ratio of the *actual* average gain <G> to the *maximum* possible average gain, i.e.,

$$\langle g\rangle = \%\langle G\rangle \;/\; \%\langle G\rangle_{max}$$

$$= (\%\langle post\rangle - \%\langle pre\rangle) \;/\; (100\% - \%\langle pre\rangle).$$

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[2]R.R. Hake, "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74 (1998); on the Web at < **http://physics.indiana.edu/~sdi/** >; see also refs 3-5.

[3]R.R. Hake, "Interactive-engagement methods in introductory mechanics courses," on the Web at < **http://www.physics.indiana.edu/~sdi/** > and submitted on 6/19/98 to the *Physics Education Research Supplement to AJP* (PERS).

[4]R. R. Hake, "Lessons from the Physics Education Reform Effort," submitted to *Conservation Ecology*, a free online journal at < **http://www.consecol.org/Journal/** >; also soon to be on line at < **http://physics.indiana.edu/~hake/** >. "FCI normalized gain results for interactive-engagement and traditional courses that are consistent with those of . . .(refs. 2 & 3) . . . have now been obtained by physics-education research groups at the Univ. of Maryland (Redish et al. 1997, Saul 1998, Redish & Steinberg 1999, Redish 1999); Univ. of Montana (Francis *et al.* 1998); Rennselaer and Tufts (Cummings *et al.* 1999); North Carolina State Univ. (Beichner *et al.* 1999); and Hogskolan Dalarna -Sweden (Bernhard 1999)." (For complete references to these papers see Sec. VB, refs. on FCI pre/post testing.)

[5]R. R. Hake, "The General Population's Ignorance of Science Related Societal Issues: A Challenge for the University," *AAPT Announcer* **30**(2), 105 (2000); on the web at < **http://www.physics.indiana.edu/~hake/** >.

2. Pretest Scores and *Hypothesized* <g>'s for Indiana University Premed Graduates of High-School Physics (HSP) Courses

For the Indiana University "pre-med" courses of ref. 2

1994 Spring: a. %<pre>(43 no HSP) = 32%
b. %<pre>(123 HSP) = 42%
$\langle g \rangle$(hypothesized*) = $\langle g_h(94) \rangle$ = (42%–32%)/(100%–32%) = 0.15

1995 Spring: a. %<pre>(45 no HSP) = 37%
b. % <pre>(164 HSP) = 43%
$\langle g \rangle$(hypothesized*) = $\langle g_h(95) \rangle$ = (43%–37%)/(100%–37%) = 0.10

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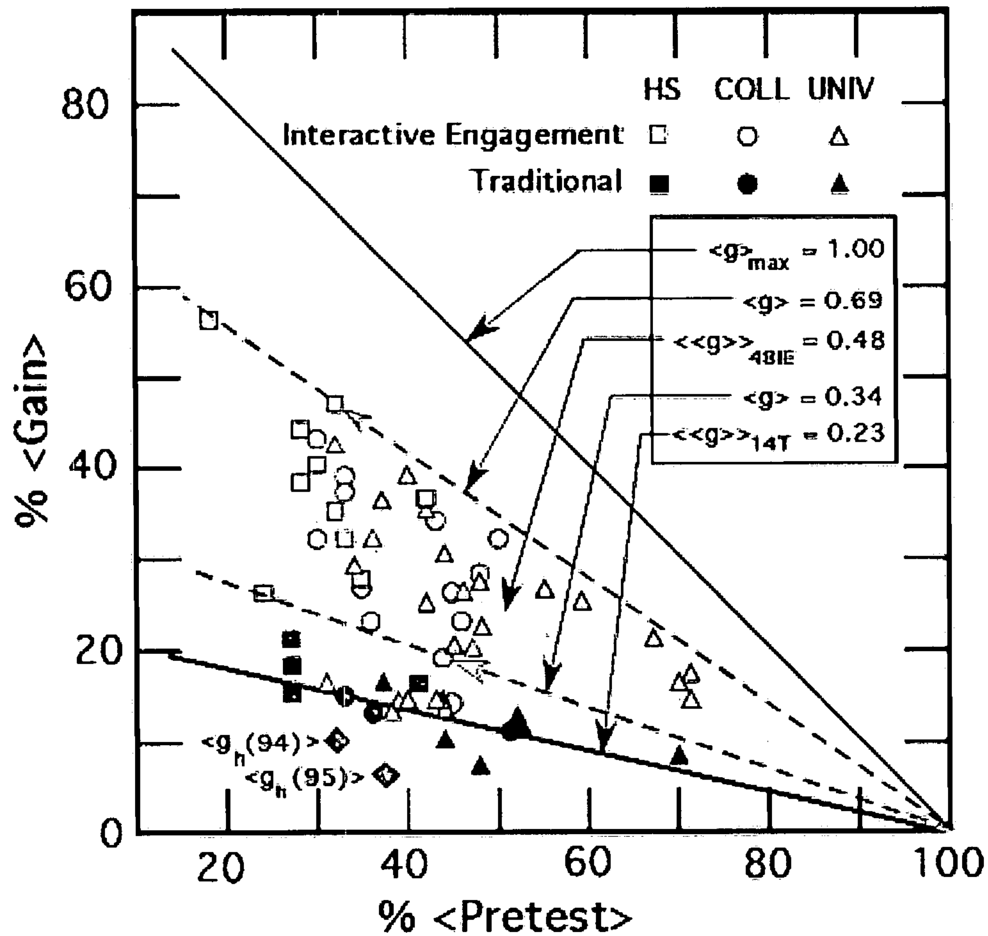
* We assume that the "b" group graduates of HSP, *before* they took HSP, would have averaged about the same as the "a" group.

3. ***Hypothesized*** **Actual Gain vs Pretest Scores ◈ for Indiana University Premed Graduates of High-School Physics (HSP) Courses** (from Fig. 1 of ref. 2 as redrawn for ref. 4)



a. Indiana University premeds who were graduates of HSP achieved *hypothesized* $\langle g \rangle$'s for their HSP courses that were even lower ($\langle g_h \rangle = 0.15, 0.10$) than the average $\langle\langle g \rangle\rangle$ (14 T) $= 0.23 \pm 0.04$sd (standard deviation) for 14 the traditional courses of the survey of ref. 1. (It might be worthwhile to examine "hypothesized $\langle g \rangle$'s" ($\langle g_h \rangle$'s) at other universities.)

b. Low $\langle g_h \rangle$'s may reflect:

(1) A rapid decrease in physics understanding in the years following HSP, as might be expected if only incoherent and loosely related bits of physics understanding had been acquired.

(2) A failure of HSP to impart much understanding of physics in the first place.

(3) Some combination of "1" and "2".

c. In any case, the results suggest the ineffectiveness of HSP to promote long-term conceptual understanding and the need for improved physics education of teachers in interactive-engagement (IE) rather than traditional (T) classes. Teachers need IE rather than T courses because they:

(1) "tend to teach the way they were taught,"
(2) should understand physics concepts.

II. Towards A Possible Partial Solution - *Curriculum S*

A. *Curriculum S* for "Synthesis" [6-8] In the words of Ken Ford [8]:

Ken Ford

"From the ..... second Ann Arbor Conference, November 1962 - came a succinct and memorable recommendation: that two kinds of curricula for physics majors be developed (to meet the needs of two kinds of students). These were named curriculum R and curriculum S. *Curriculum R* (for Research) was the then-current (and still dominant) undergraduate curriculum, whose principal aim is to prepare students for graduate study in physics. ***Curriculum S (for Synthesis) was to serve students who wanted to study physics as background for something other than physics research: business, law, medicine, teaching, some other scientific study, or just informed citizenship.***

What has happened? Sad to say, *nothing*. *Curriculum R* was already strong and is still strong. ***Curriculum S did not exist then and it does not exit now*** *(in first approximation)."* (My *italics*.)

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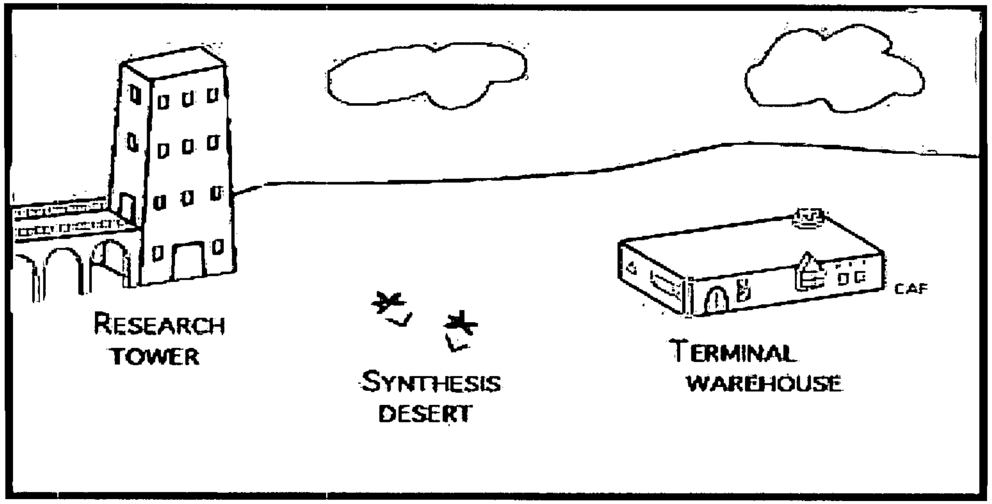
[6]Recommendations of the Second Ann Arbor Conference on Undergraduate Curricula for Physics Major," *Am. J. Phys.* **31(1)**, 1-8 (1963).

[7]E.L. Jossem, "Undergraduate Curricula in Physics: A Report on the Princeton Conference on *Curriculum S*," *Am. J. Phys.* **32**(6), 491-497 (1964).

[8]K.W. Ford, "Guest Editorial: Whatever Happened to *Curriculum S*?" *Phys. Teach.*, March 1987, pp. 138-139. See also refs. 9 & 10 on page 15 of this presentation.

"The accompanying figure shows the present situation, metaphorically.



Curriculum R is an austere four-story building, taller than it is wide. The diligent physics major climbs through its layers of requisites and prerequistes and emerges on top, ready to ascend to graduate school. (At the second-floor level is a well-traveled ramp over which engineering students - and some other students - depart after completing the first year of the curriculum.) *Next door is the* ***Curriculum S*** *desert, containing only a few scattered blossoms* . . . . another curriculum has come into being. . . ***Curriculum T*** (for terminal). . . . (with) courses on astronomy, arms control, solar energy, conceptual physics, physics of music, physics and sports, high-fidelity sound, and on and on . . . ***It is time to look again at Curriculum S*** . . . . . *We need majors with aspirations other than physics research.* Ours is an exciting field, a central part of the liberal arts.[9] It provides a useful background for many activities. Should we not promote its serious study by future teachers, lawyers, and business people. Above all, ***we need a physics major program suitable for (and attractive to) some of the teachers of the next generation - not just high-school physics teachers, but elementary*** [10,11] ***and middle school*** [10] ***teachers as well.***" (My *italics.*)

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[9]K.W. Ford, *Classical and Modern Physics* - in 3 volumes (Xerox College Publishing, 1972), esp, Vol. 1, Chapter 1, "The Nature of Physics" :
" According to one old definition, physics is the study of matter and motion. Neither this nor any other one-sentence definition can adequately reflect the mixture of creative effort, accumulated knowledge, unifying ideas, mathematical equations, philosophical impact, and practical application that comprise physics. The modern physicist has generalized the idea of matter to include the distributed energy of wave fields and the transitory energy of unstable particles; also as we shall frequently emphasize in this book, he is as much concerned with the unchanging aspects of nature as with motion and change. Yet is is true that ***the material world and the interaction of one part of it with another remain at the heart of physics. To encompass as much as possible of the behavior of matter with the simplest possible array of ideas and equations is the primary goal of the physicist*.**" (My *italics*.)

[10]K.W. Ford, "Guest Comment: Is physics difficult?" *Am J. Phys.* **57**(10), 871-872 (1989):
"*. . . . Physics is difficult in the same way that all serious intellectual effort is difficult*. Solid understanding of English literature, or economics, or history, or music, or biology – or physics – does not come without hard work. But we typically act on the assumption (and argue to our principals and deans) that ours is a discipline that only a few are capable of comprehending. The priesthood syndrome that flows from this assumption is, regrettably, seductive . . . . .
If physics is not more difficult than other disciplines, why does everyone think that it is? To answer indirectly, let me turn again to English. Six-year-olds write English and (to pick a skilled physicist writer) Jeremy Bernstein writes English. What separates them? A long, gradual incline of increased ability, understanding, and practice. Some few people, illiterates, do not start up the hill. Most people climb some distance. A few climb as far as Bernstein.
For physics, on the other hand, we have fashioned a cliff. There is no gradual ramp, only a near-vertical ascent to its high plateau. When the cliff is encountered for the first time by 16- or 17-year olds, it is small wonder that only a few have courage (and the skill) to climb it. There is no good reason for this difference of intellectual topography.
First-graders could be taught some physics . . .(ref. 11). . . , second-graders a little more, and third-graders still more. Then for the eleventh- or twelfth-grader, a physics course would be a manageable step upward. Some might choose to take it, some not, but few would be barred by lack of 'talent' or background." (My *italics*.)

[11]D. Hammer, "Physics for first-graders?" *Science Education* **83**(6),797-799 (1999);
< **http://www.physics.umd.edu/perg/cpt.html** >.

1. Some Model *Curriculum S* Programs Proposed at the Princeton Conference[7]

The intent of the original *Curriculum S* proposal was to synthesize a *single* curriculum that promoted *competence* in physics, *independence* in inquiry, *physical insight*, and talent so as to enable a student to become "a thoughtful and productive participant in a culture increasingly molded by science." [7] The three curriculum proposals below represent attempts by three working groups at the Princeton Conference to fulfill that intent. In the words of Len Jossem[7] :

"*They represent experimental skeletal structures only, and will require much additional detail before they can be be considered well defined viable programs.* The Group I outline is perhaps the closest to the traditional 'linear' structure. The Group III outline departs somewhat from this, and the Group II outline represents a parallel branching rather than serial structure." (My *italics*.)

Now, 37 years later, considering the advances in physics research, computer usage, and physics education, some additions, deletions, and modifications would, of course, be in order.

Group I Outline. Princeton Conference, December 1963

Single 4-year physics curriculum, ***R or S depending on how far one goes***, semester system assumed.

YEAR 1 (Prerequisites: Trig & College Algebra)
Math I: analytic geometry and calculus
Physics I and Lab
Exit 75-80% at this point

Course is 2-semester, multipurpose course for everyone. Student with PSSC might take 1st semester by examination. Develop vectors and calculus as needed.
Include: Newtonian synthesis, Statistical mechanics & Kinetic Theory, E & M, Relativity, Quantum Phenomena
Exclude: Statics, Hydrostatics, Rigid Body
Lab: Not tied to lectures, include circuits and geometrical optics.

YEAR 2 (Prerequisite: Math I and Physics I)
Math II
Physics II and Lab (lab not tied to lectures, includes electronics)
Include: Forces and fields, Particle Mechanics, E & M, Atomic Physics, Model systems
Exit 50%

YEAR 3 (Prerequisite: Math II and Physics II)
Mechanics (small vibrations, rigid body)
Thermodynamics and Kinetic Theory
Advanced E & M
Advanced Lab (required?)

YEAR 4
Waves Quantum Physics → Atoms & Nuclei

Options
Advanced Lab, High Energy, Solid State, Boundary Value Problems, Honors Seminar

<u>Group II Outline. Princeton Conference, December 1963</u>

Assume that the introductory course has given vocabulary and fundamental physical ideas. *Provide parallel (rather than serial) entry into courses.* Develop accessory math as needed. Courses may have some overlap but material would be seen from different point of view. Course may be 1 year or sequence of two one-semester courses. Historical and philosophical background material introduced when and where appropriate. Laboratory work complementing courses and providing introduction to design of systems. (My *italics*.)

<u>YEAR 1</u>

Good one year introductory course (e.g., First year of Group I or Group III Curriculum).

Linear Systems

Single pendulum as prototype for physics of linear systems
Harmonic motion, Mechanical-electrical systems
Coupled pendula and systems
Normal modes
Symmetry, Invariance in time ($e^{i\omega t}$)
Invariance on space translation, Boundary conditions,
  Continua-Field concepts
Band width: Fourier transforms in space and time

Statistical Physics

Elementary probability theory
Binomial, Poisson distribution
Monte Carlo Games
Random walk, diffusion
Radioactive decay
Signal-to-noise
Macro phenomena as a result of <micro phenomena>
Gas as a compound
Entropy
Temperature as dE/dS
Thermodynamics
Kinetics of reactions
Activation barrier
Catalysis
Rate determining reactions
Quantum probabilities

Group II Outline (continued).

Particle Dynamics

- One body and field of force
  - Two bodies, **F** = ma
- Momentum and Energy (kinetic and potential)
- Collisions (including Franck Hertz)
- Explore field with test body
- Planetary motion (central force problem)
- Special Relativity
- Potential well (bound levels and scattering)
- Energy (formal and variational forms)
- Angular momentum

Structure of Matter, Quantum Phenomena

↓

Atomic and Molecular Physics

- States of aggregation
- Chemical bonds
- Solids, etc.
- Nuclear physics

Physical Systems

- Design of concrete systems
- Individual project work in Lab
- Signal-to-noise
- Response time constants
- Feedback
- Electronic systems
- Examples from chemistry, biology, & engineering
- Communications
- Computation design
- Cybernetics
- How to reach a goal

Group III Outline. Princeton Conference, December 1963

YEAR 1 (Prerequisite: Trig & College Algebra)**: Mechanics, Electricity, Structure of Matter**
Classification of Experience
Development of Concepts
Galilean ideas including relativity
Newtonian mechanics, conservation laws & symmetry

Simple treatment of electricity
Atomic Structure, gases, liquids, crystals, etc.

Show carefully *how physicists organize picture of world.*
Develop math concepts as needed.

YEAR 2: Fields
(*second and third year could be taken simultaneously or perhaps in reverse order*)
More E&M through Maxwell's Equations
Wave Motion (Including mechanical systems)

Special relativity
Equivalence principle (My *italics*.)

YEAR 3: Statistical Physics
Thermodynamics
Kinetic Theory
Statistical Mechanics
Fluctuations
Quantum Ideas

Group III Outline (continued).

YEAR 4: Synthesis

A. Topics from Physics (Integrate earlier work)

- Nuclear Physics
- Symmetry and conservation Laws
- Plasmas
- Astrophysics

B. Topics that Cross Scientific Fields

- Genetics
- Molecular Biology
- Communications
- Chemical Binding
- Chemical & Biological equilibria

C. Topics that Interest Physicists and Philosophers

- Complementarity
- Verification and Explanation
- Paradoxes and their role

Laboratory considered vital. Assume most courses would have lab.

Each year to be thought of as terminal and providing students who stop there with coherent view of the essential features of physics

2. Should *Curriculum S* Contain Elements of Martin Krieger's *Physicist's Toolkit* [12] ?

a. Mathematical Tools

(1) Counting and approximation - combinatorics, statistics, asymptotics
(2) Pattern - geometry, symmetry, conservation laws
(3) Linearity and limits - calculus, optimization procedures, linear representations

Martin Krieger

b. Diagrammatic Tools

(1) Geometric and spatial - vectors and graphs
(2) Algebraic and symbolically patterned expressions - canonical forms

c. Rhetoric (Describing)

(1) Tools

(a) Media: space-time vacuum, hydrogen atom, continuous elastic medium, fluid, gas
(b) Objects: particles and excitations, oscillators, fields and waves; linear operators including differential equations and groups; correlations; properties including energy, momentum, and translation operators
(c) Interactions: objects with objects and with media (potentials, particle exchange, force field, scattering), Interaction Lagrangian, response functions

(2) Approaches:

(a) Strategies: good vacuum or ground state, equilibrium, conservation potentials; analogy and heuristic; homology of equations and solutions; ($n \log n$) vs n^2
(b) Commonplaces:
qualitative methods (e.g., Migdal): become friendly with nitty-gritty material like Coulomb wave functions; look for big contributions, the physics lies in the poles; use a classical picture, supplemented by quantum rules; things fall off, but asymptotics are important; know about potential wells, oscillators, one-particle transitions, polarizable media, ...

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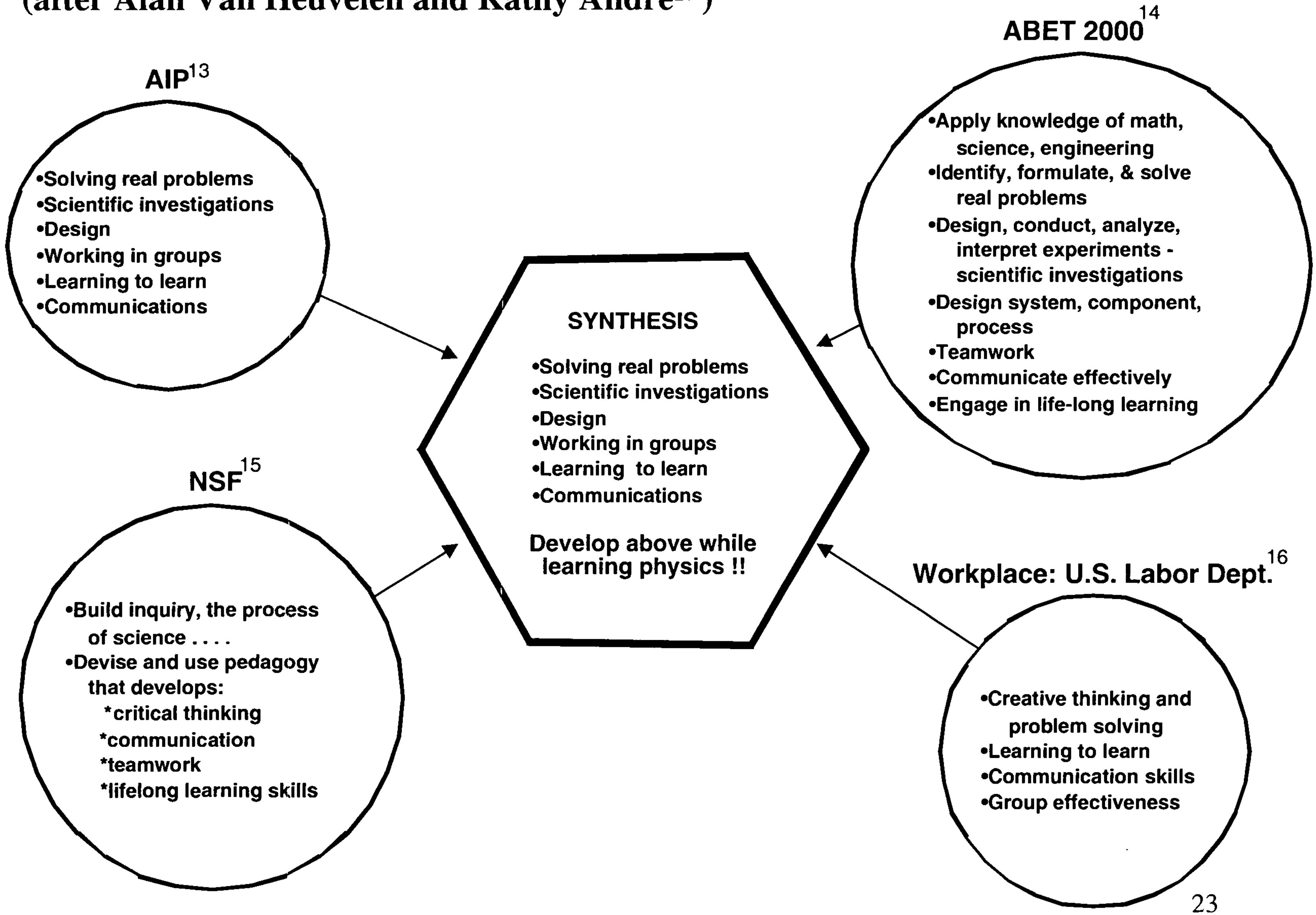
[12]M.H. Krieger,"The physicist's toolkit," *Am. J. Phys.* **55**(11), 1033-1038 (1987). Reprinted in in Tiberghien, Jossem, & Barojas (1997/98). See also M.H. Krieger, *Doing Physics: How Physicists Take Hold of the World* (Indiana University Press, 1992); *Constitutions of Matter: Modeling the Most Everyday of Physical Phenomena* (Univ. of Chicago Press, 1998).

3. Should *Curriculum S* Emphasize Skills[13-16] Needed in the Professions? (after Alan Van Heuvelen and Kathy Andre[17])



[13]R. Czujko, Statistical Research Center of AIP, “Physics Bachelors as a Passport to the Workplace: Recent Research Results”) in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE*, ed. by E.F. Redish and J.S. Rigden, (AIP, 1997). p. 213 - 223.

[14a] ABET (Accreditation Board for Engineering and Technology) < **http://www.abet.org/** >. Engineering Criteria for 2000-2001 & 2001-2002 are at < **http://www.abet.org/eac/eac.htm** >.

[14b] P. Zitzewitz, “Engineering Accreditation Changes: a Threat or an Opportunity for Physics Programs,” APS Forum on Education Newsletter, Spring 1998, pp. 1, 3 (1998); < **http://www.research.att.com/~kbl/APS/apr98/** >.

[14c] R. Ehrlich, "Engineering Deans' Opinions of Physics Courses," APS Forum on Education Newsletter, Summer 1998, pp. 2-4 (1998).

[15]*Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by Melvin George, 1996), at < **http://www.nsf.gov/cgi-bin/getpub?nsf96139** >. See also ref. 15a.

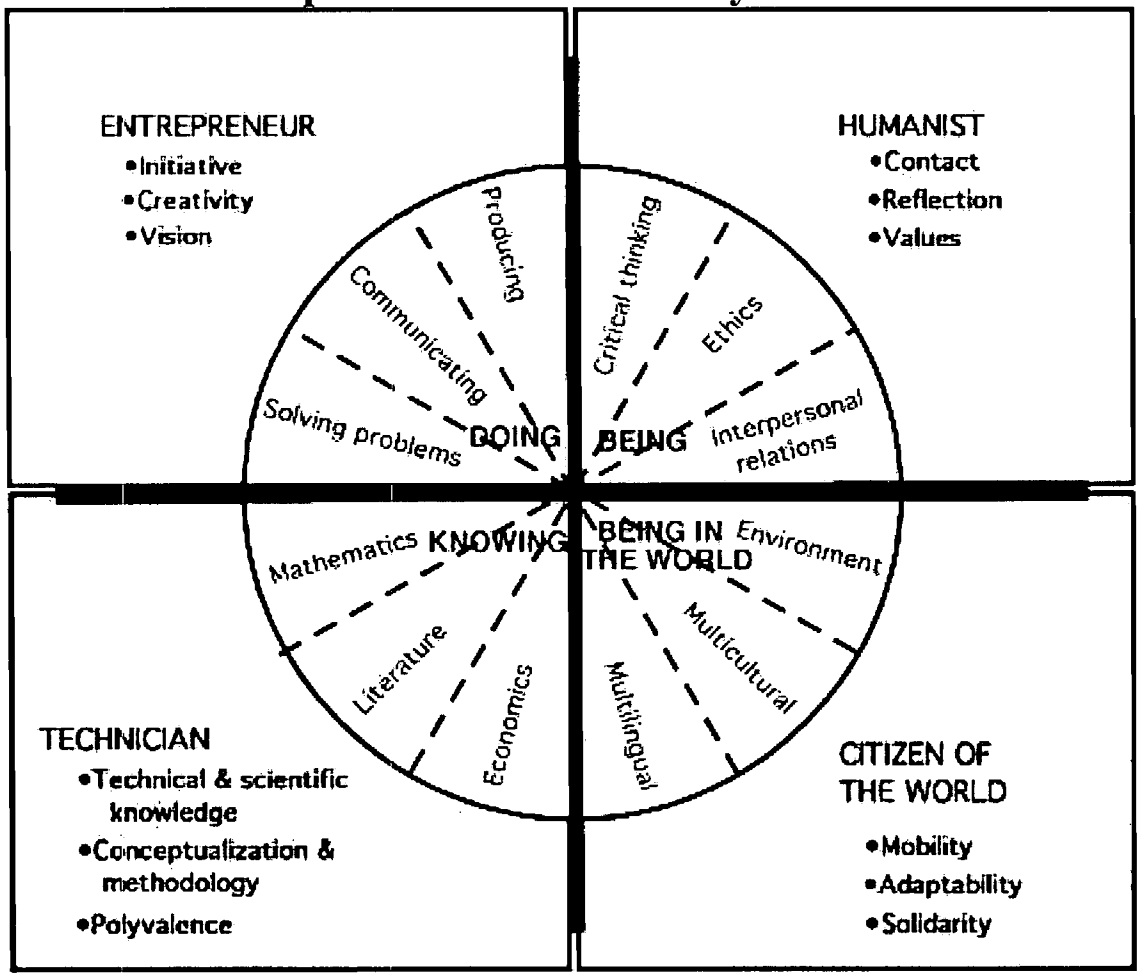
[15a]*Shaping the Future, Volume II: Perspectives on Undergraduate Education in Science, Mathematics, Engineering, and Technology*, (Advisory Committee to the NSF Directorate for Education and Human Services chaired by James M. Rosser, 1998) < **http://www.nsf.gov/cgi-bin/getpub?nsf98128** >. Contains an extensive bibliography on SME&T undergraduate education that, unfortunately, omits most of the relevant physics literature.

[16a] A.P. Carnevale, L.J. Gainer & A.S. Meltzer (U.S. Dept. of Labor), *Workplace Basics: The Essential Skills Employers Want*, (Jossey-Bass, 1990); *Workplace Basics Training Manual* (Jossey-Bass, 1991).

[16b] A.P. Carnevale, *America and the New Economy: How New Competitive Standards Are Radically Changing American Workplaces* (Jossey-Bass, 1991).

[17]A. Van Heuvelen & K. Andre, “Calculus-Based Physics and the Engineering ABET 2000 Criteria,”*Undergraduate Physics for the New Century,* Conference of Physics Chairs, 14-16 April 2000; < **http://www.aapt.org/** > .

4. Should a *Curriculum S* Complement the "University of the Future" [18]?



According to Goldschmid,[18] the four-quadrant circle "presents several discipline-independent dimensions, which should gain more importance in the curricula of the University of the Future. . . (ref. 19).. . . Complementary entrepreneurial inclinations, humanistic considerations, and multicultural skills for example, might serve the future graduate better than strictly technical knowledge. The question is how can these subjects be built into the curriculum without necessarily adding new courses? "

[18]M.L Goldschmid, "Twenty-five Years of Efforts to Improve Teaching and Learning in Higher Education: A Retrospective and a Look Ahead" in *Proceedings of the 25th International Conference on Improving University Teaching*, T. B. Massey, ed., Johann Wolfgang Goethe University; Frankfurt, Germany; 17-20 July 2000.

[19a]M.L. Goldschmid, "International University of Switzerland: A University for the Future?" in T. B. Massey, ed., *Proceedings of the 24th International Conference on Improving University Teaching*, p. 8; Brisbane, Australia, CPD, EPFL, No. 397, 1999.*

[19b]M.L. Goldschmid, "Creating a New University: A Way of Transforming Higher Education," HERDSA (Higher Education Research and Development of Australasia) Conference, Melourne, p. 4, CPD, EPFL, No. 408. 1999.*

[19c]M.L. Goldschmid, "Open Universities: Their Contributions and Challenges to Higher Education," in T. B. Massey, ed., *Proceedings of the 24th International Conference on Improving University Teaching*, p. 17; Brisbane, Australia, CPD, EPFL, No. 410, 1999.*

[19d]M.L Goldschmid, "The Promise and Challenge of Information Technology in Higher Education" in *Improving University Teaching, 22nd International Conference, Faculdade da Cidade, Rio de Janeiro, Brazil, 21-24 July, 1997*; < **http://www.net.ethz.ch/public_html/Agenda/NET_Tagung_97/Goldschmid/Goldschmid.html** >

*CPD = Chaire de Pédagogie et Didactique, EPFL = Ecole Polytechnique Fédérale de Lausanne

5. Is *Curriculum S* still worth pursuing after all these years? Answers have been given by:

a. Len Jossem[20]:

Len Jossem

"I would only ask: 'How could it not be??' and for ALL persons taking a course in physics. *How to do it is another more difficult question.* In a talk given in 1954 Robert Oppenheimer spoke about 'Prospects in the Arts and Sciences.' I quote:

'What does the world of the arts and sciences look like? There are two ways of looking at it: One is the view of the traveler, going by horse or foot, from village to village to town, staying in each to talk with those who live there and to gather something of the quality of its life . . . . The other is the vast view, showing the earth with its fields and towns and valleys as they appear to a camera carried in a high-altitude rocket. In one sense this prospect will be more complete; one will see all the branches of knowledge, one will see the arts, one will see them as a part of the vastness and complication of the whole of human life on earth.'

Physics has long since passed beyond the point at which any single person could be an expert in all of its fields, could know in an intimate way the characteristics and the quality of life in each of its villages, town, and cities. We have for the most part become specialists. But, in my view, it is important that all persons who study physics at least have had a view of its world as seen from a satellite– have seen that the villages and towns and cities are all interconnected. ***That, I think, is what synthesis is about - bringing together apparently disparate parts and showing their interconnections and interactions. And not only of the parts of physics to each other, but to the global society in which we all live***."

(My *italics and CAPS.*)

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[20]E.L. Jossem to R.R. Hake, private communication, 1/19/01. See also refs. 21-23.

[21]E.L. Jossem, Oersted Medal acceptance speech, "The World Around Us," *Am. J. Phys.* **62**(7), 589-595 (1994).

[22]E.L. Jossem, Guest Comment, "The Teaching of Physics," *Am. J. Phys.* **68**(6), 499-500 (2000).

[23]E.L. Jossem, "Resource Letter EPGA-1: The education of physics graduate students," *Am. J. Phys.* **68**(6), 502-512 (2000).

b. David Gavenda[24]:

David Gavenda

"In direct response to your question about the desirability of pursuing a true *Curriculum S*, ***I answer 'Yes'***, but one must recognize the difficulty of getting it implemented in an era when the faculty in major research institutions are becoming more specialized. On the brighter side, many deans and other higher administrators are pressuring physics departments to increase their undergraduate enrollment, *so the faculty may be forced to exhibit greater concern for the non-career physics major.*" (My *italics*.)

[24]D. Gavenda to R.R. Hake, private communication, 1/22/01.

6. Visions of physics education consistent with *Curriculum S*

a. David Goodstein[25]

David Goodstein

"My friends and colleagues across the county tell me that *the number of students majoring in physics is at its lowest point since Sputnik, more than 40 years ago*. . . . . We are in deep trouble. Our methods are obsolete, and our product is not in demand . . . . . ***If the profession of teaching physics were a business, we would be filing for bankruptcy***. . . . What can we do about it? The first step is to turn the problem around and ask, do we have any valuable assets that might be worth saving? . . . . You bet we do! ***What we have is nothing less than the wisdom of the ages. It's that vast body of knowledge, the central triumph of human intelligence, our triumph over mystery and ignorance; and to go with it we have the methods of inquiry and analysis that have produced that body of knowledge***. Our assets are so valuable that we have a solemn duty *not* to let our profession go down the drain.

The purpose of teaching physics should not be merely to clone ourselves and keep a few poor souls out of med school. ***I believe that a solid education in physics is the best conceivable preparation for a lifetime of rapid technological and social change that our young people must expect to face. The undergraduate physics major is the liberal arts education of the twenty-first century.*** Every physics department in the country ought to inscribe that motto on its walls and march under that banner. *But to make that motto a reality will require nothing less than a revolution in the way we do our jobs.*

Everything about the way we teach physics is useless for the vision I am trying to present to you. The methods, the textbooks, the language we use, all of it is designed more to get rid of the unworthy than to throw open the doors. What we need is a ***change in the mindset with which we approach the subject***. If I knew how to do all that, or ***even if I knew how to take the first step in that direction, I would certainly tell you.*** But I don't know. What I'm asking for is something that's more difficult even than physics itself." **Were the first steps taken at Ann Arbor in 1962?**[6] (My *italics*.)

[25] D. Goodstein, Oersted Medal acceptance speech, "Now Boarding: The Flight from Physics," *Am. J. Phys.* **67**(3), 183-186 (1999). See also D. Goodstein, "The Coming Revolution in Physics Education, *APS News*, June 2000, on the web at < **http://www.aps.org/apsnews/0600/060017.html** >.

b. Werner Wolf [26]

Werner Wolf

"The future of education, research, and employment in physics has been under much discussion lately. Contrary to many glowing predictions in the mid-1980's physicists graduating today face a serious shortage of jobs. . . . One solution would be to limit the number of students. This would surely be anathema to many established physicists, who believe that training in physics is and will always be valuable education . . . Another approach, advocated recently by Sheila Tobias, would be for physics educators to 'use the model of law schools to figure out how to increase the size and diversity of demand for their graduates.'[27] Implicit in this approach is the idea that '***the training of physicists must become less specialized, less reductionist, if they are to be prepared to face the real world in a wide variety of complex areas.***' Such ideas are not new. Some of us have been advocating a change in attitude for many years now,[28] but the strong employment market made it unnecessary to give widespread thought to making changes. . . .**To obtain further insight into this problem I surveyed 90 colleges and universities by mail and held telephone conversations with some two dozen colleagues in various institutions** . . . . [See Wolf's article for information on many "Multiple Path" (Sec. II B) - but not *Curriculum S* - physics major programs throughout the U.S.] . . . Educating physicists for the future will require changes at all levels, but one principle will have to be recognized: While there will always be room for physicists in narrow specialties, the number of such specialists cannot keep expanding. ***If physics is to thrive, its practitioners will have to learn to address broad classes of problems, to be flexible and deal with complexity wherever it arises. . . . With the environment for science changing ever more rapidly, adaptability and flexibility will become ever more essential.***" (My *italics*.)

26W.P. Wolf, "Is Physics Education Adapting to a Changing World?" *Phys. Today* **47**(10), 48-55 (1994).

27S. Tobias, "The Jobs Situation: Must it be More and Less of the Same?" *APS News*, April 1994, p. 8. See also S. Tobias, D.E. Chubin, & K. Aylesworth, *Rethinking Science as a Career: Perceptions and Realities in the Physical Sciences* (Research Corporation, 1995).

28W.P. Wolf in *Proc. International Conference On Postgraduate Education of Physicists*, P.J. Kennedy & K. Vacek, eds., International Committee on Physics Education, University of Edinburg, Scotland (1981), p. 123.

B. *Curriculum MP* for "Multiple Paths"

In his 1987 Guest Editorial, Ken Ford[8] wrote:

"What building should rise on the *Curriculum S* desert? Obviously it should be four stories high. But it must also be wide. Perhaps it needs express elevators to upper floors, corridors in which to move about on a given floor, stairways to go down as well as up. And it may need large atria (gaps) to keep its cost down. In mathematical skills and raw problem-solving ability, students who pursue *Curriculum S* may get no further than those on the second or third floor of the *Curriculum R* tower, but their breadth of understanding or their acquisition of certain practical skills may compensate. . . . The building site awaits attention."

Since the above was written, a new four-story building has arisen on the *Curriculum S* desert: the *Curriculum MP* (for *Multiple Paths*) tower. Instead of *Curriculum S's* top-down construction,[6,7] *Curriculum MP* has been been erected from the bottom up[29] by individual departments and driven at least partially by a desire to increase physics-major enrollments. It features two-way ramps and shuttle services to other departments and schools so as to allow physics majors to take courses in the arts and humanities, business, engineering, computing, education, etc. An outstanding early example is "engineering physics" programs at universities which have engineering schools on campus. (I received such a degree from the University of Colorado in 1950.) According to Werner Wolf,[26] in 1994 there were 27 engineering physics programs accredited by ABET[14] (Accreditation Board of Engineering and Technology). Although *Curriculum MP* provides a non-research-career option for physics majors, it does not, in general, provide a synthesis of physics so as to promote both "informed citizenship" and success in *all* vocations.

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[29] In this connection see R.J. Furnstahl & S. Rosenberg, "The Bazaar Approach to Physics Education," *AAPT Announcer* **30**(4), 120 (2000). The authors propose a curriculum development and reform model based on the "bazaar approach" to computer software development described in ref. 30. In the case of physics education, individual teachers or departments would be the counterparts of the community code experts (hackers) who contribute to software development. ***Would it be possible to construct a viable Curriculum S using the "bazaar approach" ??***

[30] Eric S. Raymond, *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary* (O'Reilly & Associates (1999); continually updated in the open source spirit at < **http://www.tuxedo.org/~esr/writings/cathedral-bazaar/** >.

1. Examples of *Curriculum MP*

a. David Gavenda of the University of Texas at Austin wrote[24]

"I well recall that meeting . . . .(1963 Princeton Conference[7] on *Curriculum S*). . . . as I had only been teaching for four years and was enthusiastic about improving physics curricula. At the time, the Univ. of Texas physics degree was very outdated, with several undergraduate courses in electronics and acoustics, but nothing in modern physics. We were beginning to add new faculty who were active researchers in atomic, nuclear, and solid state physics. There was a strong push by these new faculty to update our physics major courses and we quickly adopted the new Berkeley series when it became available and added undergraduate courses in quantum physics and its applications to atomic, nuclear, and solid state physics. I think the national support for *Curriculum R* helped us get the new courses adopted locally.

I was personally concerned that the new sequence was going to force out of our program those students who did not plan to pursue careers in physics, so I pushed hard for the adoption of a ***B.A. in physics that would require less mathematical preparation and would include some more general courses at the upper division level*** . . . see under University of Texas at Austin in the Appendix). . . . The new degree plan was adopted and I would estimate that about 20% of our graduates over the past 30 years have gone through the B.A. route.

I would be the first to admit that the upper division B.A. courses do not emphasize 'synthesis', so one could argue that this is not really a Curriculum S program. However, I do believe that many of our students who have gone on to careers in medicine and law have a much deeper understanding of science in general and physics in particular because the B.A. was available to them. (My *italics*.)

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[24]D. Gavenda to R.R. Hake, private communication, 1/22/01.

b. Art Hobson of the University of Arkansas wrote[31]:

> " . . . . we seem to have a *Curriculum S* . . .(really MP) . . . in our physics department. It's an algebra-based physics BA, requiring only 24 hours of physics/astronomy, 4 math courses, and 9 hours at the junior-senior level in a single 'special emphasis study area' that the student wishes to explore for possible future employment (e.g., music, history, business, computer science, *education*). . . .(see under University of Arkansas - Fayetteville in the Appendix) . . . .
> It forms about 20% of our physics undergraduate program, which now graduates a total of about 20 students per year. I wish more schools would offer *Curriculum S* . . .(really MP) . . . !
> *If it were standard across the country, high school students would know about this possibility, students would be friendlier towards physics, and our department would get more enrollees in the program.*" (My *italics*).

c. Examples of 36 *MP Curricula* are given in the Appendix

[31]A. Hobson to R.R. Hake, private communication, 11/22/00. See also ref. 32

[32]Gay Stewart, "Growth in Undergraduate Physics at the University of Arkansas," *APS Forum on Education Newsletter*, Fall 2000, on the web at < **http://www.aps.org/units/fed/fall2000/index.html** >.

III. Also Needed: General Reform of P-16 Education

A. Improved Attitude and Pedagogic Education of University Faculty and Administrators[3]

According to the NSF Advisory Committee (1996)[15]:

"Many faculty in SME&T at the post-secondary level continue to blame the schools for sending underprepared students to them. But, increasingly, the higher education community has come to recognize the fact that ***teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers***." (My *italics*.)

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[3] R. R. Hake, "Lessons from the Physics Education Reform Effort," submitted to *Conservation Ecology*, a free online journal at < **http://www.consecol.org/Journal/** >; also soon to be on line at < **http://physics.indiana.edu/~hake/** >.

[15] *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by Melvin George, 1996), at < **http://www.nsf.gov/cgi-bin/getpub?nsf96139** >.

B. Improved Pay, Prestige, and Working Conditions for K-12 Teachers

Don Langenberg,[33] chancellor of the University System of Maryland and former condensed-matter physicist, suggests that:

". . . . on average, teacher's salaries ought to be about 50% higher than they are now. Some teachers, including the very best, those who teach in shortage fields (e.g., math and science) and those who teach in the most challenging environments (e.g., inner cities) ought to have salaries about twice the current norm. . . . Simple arithmetic applied to publicly available data shows that the increased cost would be only 0.6% of the GDP, about one twentieth of what we pay for health care. ***I'd assert that if we can't bring ourselves to pony up that amount, we will pay far more dearly in the long run*.**"
(My *italics*.)

[33]D.N. Langenberg, "Rising to the challenge," *Thinking K-16* **4**(1),19 (2000); online as "Honor in the Boxcar" < **http://www.edtrust.org/main/reports.asp** >.

C. In-service Programs for K-12 Teachers

Several *programs** have been established over the past few years to enhance the education and pedagogical skills of in-service physics teachers, for example:

Active Learning Problem Sets (ALPS) < **http://www.physics.ohio-state.edu/~physedu/people/vanheu/index.html** >
Active Physics < **http://www.psrc-online.org/** > */Curriculum/High School/ Comprehensive Curricula/; also* < **http://www.its-about-time.com/htmls/index3.html** >
ActivPhysics <**http://www.physics.ohio-state.edu/~physedu/people/vanheu/index.html** >
Comprehensive Conceptual Curriculum for Physics (C3P) < **http://www.udallas.edu/physics/** >
Constructing Ideas in Physical Science < **http://cipsproject.sdsu.edu/** >
Constructing Physics Understanding (CPU) < **http://cpuproject.sdsu.edu/CPU/** >, also < **http://learningteam.org/** > /CPU
Cooperative Group Problem Solving < **http://www.physics.umn.edu/groups/physed/** >
Experiment Problems < **http://www.physics.ohio-state.edu/~physedu/people/vanheu/index.html** >
Hands On Physics < **http://hop.concord.org/** >
InfoMall < **http://learningteam.org/** >
Mechanical Universe < **http://www.projmath.caltech.edu/mu.htm** >
Minds On Physics < **http://umperg.physics.umass.edu/projects/MindsOnPhysics/default** >
Modeling Instruction Program < **http://modeling.la.asu.edu/modeling.html** >
Physics by Inquiry < **http://www.phys.washington.edu/groups/peg/pbi.html** >
Physics Instructional Resource Center < **http://pira.nu/** >
Physics Resources and Instructional Strategies for Motivating Students (PRISMS) < **http://www.prisms.uni.edu/** >
Physics Teachers Resource Agents (PTRA) < **http://www.aapt.org/programs/ptra/ptra.html** >
Powerful Ideas in Physical Science < **http://www.psrc-online.org/** > */Curriculum/College-University/ Pre-service Teacher Education/*
Socratic Dialogue Inducing Labs < **http://www.physics.indiana.edu/~sdi** >
Tools for Scientific Thinking < **http://www.vernier.com/cmat/tst.html** >
Tutorials in Physics < **http://www.phys.washington.edu/groups/peg/tut.html** >
Workshop Physics < **http://physics.dickinson.edu/** > /Workshop Physics
Workshop Science < **http://physics.dickinson.edu/** > /Workshop Science Project

*See also the AAPT's *Physical Science Resource Center* < **http://www.psrc-online.org/** >.

D. PhysTEC [34,35] (Physics Teacher Education Coalition)

According to Stein & Hehn,[34] PhysTEC is an AAPT/NSF project ". . . to increase the role of physics departments, *in collaboration with education departments* to create more and better-prepared future teachers. Over the next five years . . .(PhysTEC) . . . will be established with an initial membership of more than 20 universities and colleges that share an increasing interest in revising their teacher preparation program." (My *italics*.)

APS Education Director Fred Stein heads out the door on another site visit for the PhysTEC program.[35]

[34] F.M. Stein & J.G. Hehn, "Re-Preparing Physics Teachers," *AAPT Announcer* **30**(4), 95 (2000); see also < **http://positron.aps.org/educ/undergrad/main-phystec.html** >.

[35] *APS News Online*, "Site Visits To Identify Strong Candidates for New Education Program," October 2000; online at < **http://www.aps.org/apsnews/1000/100001.html** >.

E. Two-year "Professional Master's Degrees" (PMD)[36-41]

"Its time to diversify not just the students we seek to attract to physics, but also the range of careers we prepare them for and encourage them to pursue." [36]

According to listings at < **http://www.ScienceMasters.com** >, Physics PMD's are offered at :

Michigan State (*Modeling and Simulations*)
Univ. of Southern California (*Physics for Business Applications*)
University of Arizona (*Applied and Industrial Physics*)
University of California-Irvine (*Chemical and Material Physics*)
Texas Tech University (*Applied Physics with Internships in the Semiconductor Industry*)
University of Arkansas-Fayetteville (*Applied Physics*)

No PMD's in *Physics Education/Teaching* are listed above. Since the need for greater professionalization in K-12 science teaching is crucial (see.e.g., the Glenn Report[42]) it is fortunate that MS programs in this area exist at Arizona State University[43] and the University of Virginia.[44] In addition, the well-known Master of Arts in Teaching (MAT) can serve to enhance physics teaching professionalism if properly implemented.[45]

Hammer, Czujko, and Norton (HCN)[40] define a PMD program as one that addresses the current n eeds of the economy as well as addresses the needs of students by providing both fundamental knowledge and specialized skills. Fundamental knowledge is the foundation on which students will be able to build throughout their working lives and the specialized skills will enable students to get their careers started immediately after graduation. They have h ave identified the PMD physics programs in these categories: 22 strongest, 17 strong but falling short of their produ ctivity threshold, and 22 with strong features but identified too recently to be evaluated. A survey of the 22 strongest disclosed the following PMD s in education or closely related fields:

1. Ball State < **http://www.bsu.edu/csh/physics/prog.htm** >: Master of Arts in Education in Physics, EdD in Science and EdD in Science ED.
2. Columbia University < **http://www.columbia.edu/~asb3/philphys/philphys.html** >: Master of Arts Program in Philosophical Foundations of Physics.
3. Northern Illinois University < **http://www.physics.niu.edu/www_root/public/physgrad.html** >: Secondary Education.
4. University of Vermont < **http://www.uvm.edu/%7Ephysics/gradpage.html** >: Master's of Science for Teachers of Science.
5. University of Washington < **http://www.phys.washington.edu/Department/Gradweb/Eve_GeneralInfo.html** >: Master's Program in Physics Education.

[36]S. Tobias, “So, What Else Can I Do With a Physics Major?” *AAPT Announcer* **30**(4), 122 (2000).

[37]S. Tobias, D. Chubin, and K. Aylesworth, *Rethinking Science as a Career* (Research Corporation, 1995), esp. Chap. 6, "Reinventing the Master's Degree and Revitalizing Undergraduate Programs."

[38]M. Jensen, "Reinventing the Science Master's Degree,” *Science* **284**, 1610-1611 (1999).

[39]J. Kumagai, "Professional Master's Degrees Promise Quicker Entry Into Industry Jobs," *Phys. Today* **52**(6), 54-55 (1999).

[40]P.H. Hammer, R. Czujko, and S.D. Norton "Professional Master's Degree Programs in Physics." *AAPT Announcer* **30**(4), 83 (2000); < http://www.aip.org/professionalmasters/index.htm >.

[41]P.H. Hammer, R. Czujko, and S.D. Norton ”Mastering Physics for Non-Academic Careers" on the web at < **http://www.aip.org/professionalmasters/profmshigh.htm** > and < **http://www.aip.org/professionalmasters/index.htm** >.

[42]Glenn Commission Report, *Before It's Too Late: A Report to the National Commission on Mathematics and Science Teaching for the 21st Century*; online at < **http://www.ed.gov/americacounts/glenn/toc.html** >. See also “Glenn Commission Report,” *APS Forum on Education Newsletter*, Fall 2000, on the web at < **http://www.aps.org/units/fed/fall2000/index.html** >

[43]Arizona State University has inaugurated a Master of Natural Sciences (MNS) program aimed at “upgrading the professional development of high school science teaching that includes contemporary science, effective pedagogy, use of technology, leadership skills, and community building.” See < **http://modeling.la.asu.edu/MNS/MNS.html** >.

[44]The University of Virginia offers a “Master of Arts in Physics Education” to address the needs of middle and high-school physics teachers. See < **http://www.phys.virginia.edu/Scripts/Research/researchers-by-area.asp?aID=education** >.

[45]The MAT is usually offered jointly by a physics department (for the physics) and a school of education (for the pedagogy). Excellent MAT programs can and do exist where there is mutually beneficial interaction between physics-education researchers and education-school faculty as prescribed in ref. 4 on p. 9 of this presentation.

F. Glenn Commission Proposals [42]

< http://www.ed.gov/americacounts/glenn/toc.html >

Requests ***5 billion dollars*** in the first year to initiate:

a. Establishment of an ***ongoing system to improve the quality of mathematics and science teaching in grades K–12***.

b. Significant increase in the number of mathematics and science teachers with ***improved quality of their preparation***.

c. Improvement of the working environment and so as to ***make the teaching profession more attractive for K–12 mathematics and science teachers.***

(My *italics*.)

[42]Glenn Commission Report, *Before It's Too Late: A Report to the National Commission on Mathematics and Science Teaching for the 21st Century*; online at < **http://www.ed.gov/americacounts/glenn/toc.html** >. See also "Glenn Commission Report," *APS Forum on Education Newsletter*, Fall 2000, on the web at < **http://www.aps.org/units/fed/fall2000/index.html** >

IV. Conclusions

A. ***There is a desperate national need for improved science education of P-12 teachers***.

B. A possible partial solution is the implementation of *Curriculum S* for physics majors who aspire to non-research careers ***including P-12 teaching***.

C. Although there are now many non-research-career *Curriculum MP's* (Multiple Path) for physics majors, these do not, in general, provide a *synthesis* of physics intended to promote both "informed citizenship" and success in *all* vocations.

D. *How* to implement *Curriculum S* is a difficult problem - leads have been provided by (1) the 3 model curriculum outlines proposed by the 1964 Princeton conferees, (2) Martin Krieger's *Physicist's Toolkit*, (3) the Van Heuvelan-Andre synthesis of needed skills, (4) Marcel Goldschmid's envisaged "University of the Future," and (5) Furnstahl & Rosenberg's suggestion of a "bazaar approach" to curriculum development.

E. In addition to improvement of B.S./B.A. physics-major curricula, more professional M.S./M.A. programs in physics/science education should be instituted.

F. ***Also needed is the general reform of K-16 education***.

G. ***It is time to implement Curriculum S !***

Appendix

Thirty-six examples of physics departments* with MP (Multiple Path)physics major curricula:

1. **University of Arizona**
   < http://www.physics.arizona.edu/physics/student/undergrad.html >

2. **Arizona State University < http://phy.asu.edu/student/ugraduate/index.html >**

3. **University of Arkansas** (Fayetteville) **< http://www.uark.edu/depts/physics/ >**

4. **Ball State < http://www.bsu.edu/csh/physics/prog.htm >**

5. **California State University** - Chico **< http://www.phys.csuchico.edu./ >**

6. **California Institute of Technology**
   < http://www.admissions.caltech.edu/academics/options.htm >

7. **Carthage College < http://www.carthage.edu/departments/physics/the_major.htm >**

8. **University of Colorado < http://physics.colorado.edu/ugrad.html >**

9. **Colorado School of Mines**
   < http://www.mines.edu/Academic/physics/undergrad_pgm/index.html >

10. **Colorado State University**
    < http://www.physics.colostate.edu/Undergraduate/undergrad.html#progs >

11. **Cornell University**
    < http://www.physics.cornell.edu/physics/undergradstudies/undergrad.program.html >

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*For some physics department URL's worldwide see **< http://www.physlink.com/departments.cfm >**
For U.S. university URL's see **< http://www.clas.ufl.edu/CLAS/american-universities.html >**.

12. **Florida State < http://www.physics.fsu.edu/ >**

13. **Georgia Institute of Technology**
< http://www.physics.gatech.edu/academics/undergrad.html >

14. . **Harvard < http://www.registrar.fas.harvard.edu/handbooks/student/chapter3/physics.html >**

15.. **University of Illinois**
< http://www.physics.uiuc.edu/Education/undergrad/prospective/index.html >

16.. **Illinois State < http://www.phy.ilstu.edu >**

17. **University of Kansas**
< http://www.phsx.ukans.edu/AcademicOverview.html >

18. **Louisiana State Univ. < http://www.phys.lsu.edu/dept/ungrad/ungrad.html >**

19. **Miami University (Ohio) < http://www.cas.muohio.edu/~physicsweb/ >**

20. **MIT < http://web.mit.edu/physics/acad_programs/undergrad_study.htm >**

21. **Northern Arizona University < http://www.nau.edu/~service/studentinfo/physastr.html >**

22. **University of Northern Iowa < http://www.physics.uni.edu/programs.html >**

23. **Ohio State < http://www.physics.ohio-state.edu/undergrad/undergraduate_flyer.html >**

24. **Penn State University < http://www.phys.psu.edu/undergrad/phys_info.html#physics_at_psu >**

25. **Purdue University**
< http://www.physics.purdue.edu/education/undergrad/underprog.html >

26. Sonoma State University < http://www.phys-astro.sonoma.edu/catalog/ >

27. University of Maryland
< http://www.physics.umd.edu/studinfo/ugrad/uguide/program.html#theph1 >

28. University of Michigan < http://www.physics.lsa.umich.edu/undergrad >

29. Moorehead State < http://physweb.mnstate.edu/ >

30. Oregon State < http://www.physics.orst.edu/programs/undergradprog.html >

31. Rutgers < http://www.physics.rutgers.edu/descr/descr-ug-program.html#DESCR >

32. University of Texas at Austin < http://www.ph.utexas.edu/undergrad_req.html >

33. University of Virginia
< http://www.phys.virginia.edu/Education/Programs/Degrees/ >

34. Western Michigan University
< http://tesla.physics.wmich.edu/ugradprogram/index.htm >

35. Xavier University (Louisiana) < http://www.xula.edu/physengr_dept/index.html >

36. Yale University < http://www.yale.edu/ycpo/ycps/M-P/physcsFM.html >

Acknowledgments

I am indebted to Len Jossem for information on the early Ann Arbor and Princeton history of the *Curriculum S* effort, and for emphasizing to me the crucial importance of the "synthesis" aspect. I thank David Gavenda for his comments on the 1964 Princeton conference and the origin and success of the B.A. physics program at the Univ.of Texas at Austin. I have also benefited from comments on multiple-path physics-major programs and Master's Degree teaching programs at their institutions by Art Hobson of the Univ. of Arkansas - Fayetteville; Joe Tenn of Sonoma State University; Dan MacIsaac of the University of Northern Arizona; David Hestenes of Arizona State University; and speakers at the January 2001 San Diego AAPT meeting[46,47]: Ingrid Novodvorsky of the University of Arizona, Richard Lindgrin of the University of Virginia, Carl Wennig of Illinois State University, Paul Sokal of Pennsylvania State University, David Kagan of California State University - Chico, Lawrence Escalada of the University of Northern Iowa, Jane Jackson of Arizona State University, and Kevin Crosby[47] of Carthage College. For more information on the above programs see the abstracts in refs. 46 and 47 and the web pages listed in the Appendix. I also thank Sheila Tobias[48] and Bo Hammer[49] for comments on Professional Master's Degree Programs, Fred Stein for some of the references in Sec. V, and Rick Reis for providing a copy of Goldschmid's article.[18]

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[46] Session DF, "Preparation of Pre-College Teachers in the 21st Century, Part II," *AAPT Announcer* **30** (4), 102-104 (2000).

[47] K.M. Crosby, D.N Arion, and J.M. Quashnock, "Reinventing the Physics Major at a Small College," *AAPT Announcer* **30** (4), 121 (2000).

[48] S. Tobias to R.R. Hake, private communication, 1/9/01.

[49] P.H. Hammer to R.R. Hake, private communication, 1/19/01.

V. References* ‡ ◊

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* An asterisk before a reference in this Sec. V indicates that the reference also appears in Sec. I - IV.

‡ Citations within any reference in this Sec. V to other references in Sec. V are indicated as e.g., "Smith & Jones (1993)". To locate that reference do a keyword search for either "Smith" or "Jones" by clicking on the binocular icon at the top the portable document file.

◊ A point of entry into the vast literature and web resources relevant to education reform. See also R.R. Hake, "Using the Web to Promote Interdisciplinary Synergy in Undergraduate Education Reform," *AAPT Announcer* **30**(4), 120 (2000), soon to be at < **http://www.physics.indiana.edu/~hake** >.

A. TIMSS

American Federation of Teachers (AFT). Undated. *TIMSS* < **http://www.aft.org/timss/index.htm** >, especially "New! Drs. James Stigler and Harold Stevenson answer questions about the TIMSS instructional videotapes," available as "trns.pdf."

American Institute of Physics, American Physical Society, American Association of Physics Teachers, American Astronomical Society, Acoustical Society of America, American Association of Physicists in Medicine, American Vacuum Society. 1999."Joint Statement on the Education of Future Teachers; < **http://www.aip.org/education/futeach.htm** >.

Beatty, A. 1997. ed., Committee on Science Education K-12; *Learning from TIMSS: Results of the Third International Mathematics and Science Study, Summary of a Symposium* (National Research Council,); < **http://books.nap.edu/catalog/5937.html** >.

Beatty, A., L.W. Paine, and F.O. Ramirez, eds. 1999; Board on International Comparative Studies in Education, *Next Steps for TIMSS: Directions for Secondary Analysis* (National Research Council); < **http://books.nap.edu/catalog/6433.html** >

***Bowen, S.** 1998. "TIMSS - An Analysis of the International High School Physics Test," *APS Forum on Education Newsletter*, Summer, pp. 7-10; < **http://www.research.att.com/~kbl/APS/aug98/TIMSS2.htm** >.

Bracey, G.W. 1998a, "Tinkering with TIMMS," *Phi Delta Kappan,* September; < **http://www.pdkintl.org/kappan/kbra9809.htm** >.

Bracey, G.W. 1998b, "TIMSS, Rhymes with 'Dims,' As in 'Witted ? *Phi Delta Kappan,* May. Here and above, Bracey, as does Neuschatz (1999), faults TIMSS for trans-national comparisons of students with inequivalent average ages and course experience. < **http://www.pdkintl.org/kappan/kbra9805.htm** >.

Colwell, R.R. 2000. TIMMS-R Press Conference; < **http://www.nsf.gov/od/lpa/forum/colwell/rc001205timss.htm** >: "TIMSS-R gives an in-depth examination of education practices in the United States. ***Weaknesses are obvious, especially in training our elementary and middle school teachers.*** Strategies to address the weaknesses detected in math and science education can thus be developed. ***Today's results highlight the importance of teacher quality. U.S. teachers of eighth grade mathematics and science are less likely to have majors or minors in the fields they teach than their counterparts abroad.*** This finding is consistent with results from the 1995 TIMSS study. We know that kids can't learn what their teachers don't really understand. The previous TIMSS study also revealed the importance of rigorous mathematics and science curricula for high student achievement. Both of these principles are being integrated into NSF's education efforts. Lessons learned from the TIMSS-R will shape future NSF investments. . . . .In closing let me add one final point. ***For the first time since Sputnik, education is the number one issue on the national agenda. The TIMSS-R results may not be startling or new, and may even be a little depressing, but our response should embody the idea of 'sustained urgency.' That is, we need to strengthen our resolve to make the wisest of investment for the future of our nation."*** (My *italics*.)

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* An asterisk before a reference indicates that the reference also appears in the body of *"Is it Finally Time to Implement Curriculum S*"*

Gonzales, P., C. Calsyn, L. Jocelyn, K. Mak, D. Kastberg, S. Arafeh, T. Williams, and W. Tsen. 2001. *Pursuing Excellence: Comparisons of International Eighth-Grade Mathematics and Science Achievement from a U.S. Perspective, 1995 and 1999.* (NCES 2001-028. Washington, DC: U.S. Government Printing Office); < **http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2001028** >

International Study Center at Boston College. 2001. < **http://www.timss.org/** >. See especially under TIMMS - Repeat 1999 < **http://isc.bc.edu/timss1999.html** > and "TIMSS- 2003."

***Leath, A.T.** 2001. "TIMSS Report Provides International Comparisons in 8th-grade Science & Math," *APS News*, February; < **http://www.aps.org/apsnews/** >.

National Center for Educational Statistics. Undated. *Highlights from the Third International Mathematics and Science Study-Repeat (TIMSS-R)*; < **http://nces.ed.gov/timss/timss-r/highlights.asp** >.

National Center for Educational Statistics. Undated. *Third International Mathematics and Science Study* [includes information on TIMMS-R (Repeat); < **http://nces.ed.gov/timss/** >.

Eisenhower National Clearing House. Undated. TIMSS Resources. < **http://www.enc.org/topics/timss/** >. See especially "Education Experts React to TIMMS; < **http://www.enc.org/topics/timss/additional/** >. See, e.g., Elmore (1997) below.

Elmore, R.F. 1997. "Education Policy and Practice in the Aftermath of TIMSS" < **http://www.enc.org/topics/timss/additional/documents/0,1946,CDS-000163-cd163,00.shtm** >: "In this paper, I have argued that the TIMSS findings advanced the debate in the U.S. about policy and practice in response to standards-based reform by calling attention to the gap between educational practice and student performance, on the one hand, and the aspirations of reformers, on the other. The reality of American schooling, I have argued, is a world driven by dispersed control and political pluralism, and the challenge of reformers is to introduce external standards for content and student performance into this world, rather than to displace it. ***The pivotal problems of standards-based reform, I have argued, are knowledge, skill, and incentives, and the solution to these problems will require new conceptions of everyone's role in the system -- from policymakers and high-level administrators to teachers and students and families***. The key change is bringing the discourse of policy and practice closer together by engaging policymakers and practitioners in mutually accountable actions around knowledge, skill, and results. ***The institutional and political patterns that have produced the results portrayed in the TIMSS findings are deeply rooted in the American system of school governance and management. They will not be changed without hard and focused work.***" (My *italics*.)

National Research Council, 1996; Mathematical Sciences Education Board and Committee on Science Education K-12, *Mathematics and Science Education Around the World: What Can We Learn From The Survey of Mathematics and Science Opportunities (SMSO) and the Third International Mathematics and Science Study (TIMSS)?* < **http://books.nap.edu/catalog/5508.html** >.

***National Research Council (NRC).** 1999a. *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education* (National Academy Press, 1999); < **http://www.nap.edu/catalog/9605.html** >:

National Science Foundation. 1999b. *Preparing Our Children: Math and Science Education in the National Interest, NSB 99-31* < **http://www.nsf.gov/cgi-bin/getpub?nsb9931a** >: "According to the Third International Mathematics and Science Study (TIMSS), U.S. students are not taught what they need to know. ***Most U.S.high school students take no advanced science, with only one-quarter enrolling in physics, one-half in chemistry***. From the TIMSS analysis we also learned that mathematics and science curricula in U.S. high schools lack coherence,depth,and continuity,and cover too many topics in a superficial way . . . . When we compare our K-12 schools and curricula in light of the TIMSS results, ***we find many teachers lacking good content preparation and, in the aggregate, a muddled and superficial curriculum.*** Even excellent pedagogy cannot inspire learning what the world's best-performing children are expected to know in these circumstances. Amidst the diversity of students and systems —large and small, wealthy and disadvantaged, urban and suburban and rural —***there is an overarching reality: in too many American schools there is too little quality science and mathematics being taught and learned."*** (My *italics*.) Contains a good set of TIMMS references.

National Science Teachers Association (NSTA). 2000. Statement Regarding the TIMSS - Repeat (TIMSS-R); < **http://www.nsta.org/pressrel/timss-r.asp** >: "It is undoubtedly disappointing that students are not making significant improvements in science achievement. Unfortunately, the same conditions exist today that existed five years ago when TIMSS was first administered. ***We must change the working environment of science teachers, and, among other things, ensure they receive professional training and development that is afforded professionals in other fields. If we don't, we are bound to see the same results in five more years.***" (My *italics*.)

***Neuschatz, M.** 1999 "What can the TIMSS teach us?" *The Science Teacher* 66(1), 23-26.

***Schwartz, R.B.** 1999. "Lessons from TIMSS," *Hands On** 21(1), 4 (1999); < **http://www.terc.edu/handsonIssues/s98/schwartz.html** >. *Hands On* is a publication of TERC - Technical Education Research Center < **http://www.terc.edu** >. Schwartz is president of ACHIEVE (2001), and on the faculty of the Harvard Graduate School of Education.

Shanker, A. 1996. "A Commonsense Approach"; < **http://www.aft.org/stand/previous/1996/120196.html** >.

"TIMSS calls into question a number of fashionable explanations and remedies for mediocre student achievement. For one thing, we are not going to raise student achievement by instituting a longer school day or school year: TIMSS tells us that U.S. students already spend more time in class than German or Japanese students. Nor will it help to give our students more homework or somehow induce them to turn off the TV. TIMSS shows that American students get more homework than Japanese students and watch no more television than they do. Some obvious solutions we've heard about turn out not to be so obvious after all.

However, TIMSS is unequivocal about what the school systems of successful nations share--and it is not vouchers or charter schools or any of the other jazzy schemes that we are being urged to try. ***Nearly all of these nations have clear and rigorous national or state curriculum standards, and everything they do in the schools is hitched to these standards. We do not have such standards.***

When TIMSS researchers analyzed U.S. textbook and curriculum samples, they found that what our students are taught in math and science is fragmented and unfocused. This should be no surprise given the fact that our national system still consists of 15,000 school districts, each making its own decisions about curriculum. Textbooks in standards-based systems focus on what the standards say that students must know. ***Here, where textbook publishers want to accommodate as many different school curriculums as possible, we have textbooks crammed with topics, nearly all treated in a superficial way. Since districts rely on these textbooks, it is no wonder that the curriculum is, as TIMSS says, 'a mile wide and an inch deep.'*** . . . .

We have made some progress in bringing standards and stakes for students to this country, but supporters face an uphill battle. In the meantime, 'innovative' solutions to our school problems grab media and political attention--vouchers, charter schools, private management of public schools (remember EAI?). They often grab the funding, too. ***TIMSS demonstrates once again that the answer is not one of these new or sexy or headline-making proposals. High standards of achievement with stakes attached are an old-fashioned, commonsense approach that is not the stuff of slogans. But it works in other successful school systems, and it can work here***" (My *italics*.)

Stevenson, H.W. 1998a. "A TIMMS Primer" < **http://www.edexcellence.net/library/timss.html** >.

Stevenson, H.W. 1998b. "A Study of Three Cultures: Germany, Japan, and the United States, *Phi Delta Kappan,* March. < **http://www.pdkintl.org/kappan/kste9803.htm** >.

Stigler, J.W. & J. Hiebert, 1997. "Understanding and Improving Classroom Mathematics Instruction: An Overview of the TIMSS Video Study," *Phi Delta Kappan*, September; < **http://www.pdkintl.org/kappan/kstg9709.htm** >.

***Stigler, J.W. & J. Hiebert,** 1999. *The Teaching Gap* (Free Press); see also < **http://www.lessonlab.com/teaching-gap/** >. Contains an illuminating analysis of TIMSS videotapes.

U.S. Dept. of Education. 1998. *12th-Grade Results of Third International Math and Science Study (TIMSS)* < **http://www.ed.gov/inits/TIMSS/** >.

U.S. Dept. of Education, National Center for Eduational Statistics, National Science Foundation, Undated, TIMSS < **http://www.forum.swarthmore.edu/social/timss/intro.html** >.

U.S. National Research Center for TIMSS, Michigan State University. Undated. < **http://ustimss.msu.edu/** >. See especially under "TIMSS Links and Resources."

Wang, J. 1998. "A Content Examination of the TIMSS Items," *Phi Delta Kappan*, September; < **http://www.pdkintl.org/kappan/kwan9809.htm** >.

B. FCI Pre/post Testing

Beichner, R., L. Bernold, E. Burniston, P. Dail, R. Felder, J. Gastineau, M. Gjertsen, and J. Risley. 1999. “Case study of the physics component of an integrated curriculum.” *Physics Ed. Res.*, supplement 1 to the *Am. J. Phys.* **67**(7), S16-S24.

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Hake R.R. 1992. “Socratic pedagogy in the introductory physics lab. *Phys. Teach.* **30,** 546-552. A version updated on 4/27/98 is at < **http://physics.indiana.edu/~sdi/** >.

***Hake R.R.** 1998a. "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74; < **http://physics.indiana.edu/~sdi/** >.

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***Hake. R.R.** 2001a. "Lessons from the Physics Education Reform Effort," submitted to *Conservation Ecology*, a free online journal at < **http://www.consecol.org/Journal/** >; also soon to be on line at < **http://physics.indiana.edu/~hake/** >. Gives references to articles by physics education research groups whose FCI normalized gain results for interactive-engagement and traditional courses are consistent with those of Hake (1998a,b). The groups are are at: Univ. of Maryland (Redish et al. 1997, Saul 1998, Redish & Steinberg 1999, Redish 1999); Univ. of Montana (Francis *et al.* 1998); Rennselaer and Tufts (Cummings *et al.* 1999); North Carolina State Univ. (Beichner *et al.* 1999); and Hogskolan Dalarna -Sweden (Bernhard 1999). References to those papers are given in this section VB. The consistency of pre/post test results calls into serious question the common dour appraisals of pre/post test designs [see, e.g., Cook & Campbell(1979), Cronbach & Furby 1970)].

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Redish, E.F., J.M. Saul, R.N. Steinberg. 1997. "On the effectiveness of active-engagement microcomputer-based laboratories." *Am. J. Phys.* **65**(1):45-54; < **http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html** >.

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Saul, J.M. 1998. *Beyond problem solving: evaluating introductory physics courses through the hidden curriculum.* Ph.D. thesis, Univ. of Maryland.

Tobias, S. & R.R. Hake. 1998. "Professors as physics students: what can they teach us?" *Am. J. Phys.* **56**(9), 786-794.

C. Reform of P-16 Education

1. Statements & Reports by Societies, Working Groups, and Agencies

AAAS. 1993. American Association for the Advancement of Science, *Benchmarks for Science Literacy - Project 2061*, (Oxford Univ. Press, 1993); see at < **http://project2061.aaas.org/tools/benchol/bolframe.html** >.

AAAS. 1998. American Academy of Arts and Sciences. 1998 *Education yesterday, education tomorrow. Daedalus* **127**(4); For a description see < **http://daedalus.amacad.org/inprint.html** >. Contains essays by researchers in education and by historians of more rapidly developing institutions such as power systems, communications, health care, and agriculture. Sets out to answer a challenge posed by Kenneth Wilson: "If other major American 'systems' have so effectively demonstrated the ability to change, ***why has the educational 'system' been so singularly resistant to change?*** What might the lessons learned from other systems' efforts to adapt and evolve, have to teach us about bringing about change - successful change - in America's schools?" See also < **http://www.physics.ohio-state.edu/~redesign/** >. (My *italics*.)

AAPT. Undated. American Association of Physics Teachers, "A Model for Reform Two-Year Colleges in the Twenty-First Century: Breaking Down Barriers," < **http://www.psrc-online.org/** >/"Two-Year Colleges. . . "

AAPT. Undated. American Association of Physics Teachers. John Hubisz. "To Improve the K-12 Physics Curriculum", < **http://www.aapt.org/** >/ "AAPT Planning for the Future"/"Improvement of K-12 Physics Curriculum" : "The AAPT needs to consider capital "P" Physics (natural philosophy) as a goal for reaching all children. Instead of a collection of physics courses that some few may take, ***we need program of physics that is a part of the education of every child in every school year***. Instead of individual courses that often repeat material at a more sophisticated mathematical level we should develop a physics continuum of material. . . . . The Paideia Program. . . .< **http://www.paideia.org/** > . . . . . is an excellent model of a way to teach this program, but when it comes to science, the Paideia Program folks need help and we can provide that help with selected readings from the masters. Teachers unaware of this approach would do well to read *Reforming Education* by Mortimer J. Adler . . .Adler (1977). . .Providing examples of the use of physics in forensic detective work, automotive applications, archeology, history, sports events, medicine, around the home, on the job, dispelling pseudoscience, and so on, ***will show that Physics impinges on the students' daily lives and is valuable whether or not they choose a scientific field of study. . . . The large university physics departments historically have not emphasized the preparation of teachers. We must improve that situation***. The results of the working conference on "The Role of Physics Departments in Preparing K- 12 Teachers" sponsored by The University of Nebraska-Lincoln, the AIP, the APS, the AAPT, and the Nebraska EPSCoR held at UN-L.. . . . < **http://physics.unl.edu/~diandra/DLP/TeachersConference.html** > . . . should help us determine a road to travel in this regard."

(My *italics*.)

AAPT. 2000. American Association of Physics Teachers, L.M. Adair & C.J. Chiaverina, "The Preparation of Excellent Teachers at All Levels," < **http://www.aapt.org/** >/"AAPT Planning for the Future" / "Preparation of Excellent Teachers at All Levels" "America's elementary teacher preparation in science falls short of the mark set by the NSTA. . . . . The NSTA recommends that elementary teachers have a minimum of one college course in each of the three science areas-biology, physical science and earth science and coursework in science education. ***Roughly half of the elementary teachers meet this standard***. According to Roman Czujko, Director, Statistical Research Center, American Institute of Physics, on average, ***students majoring in elementary education take the least number of science courses. This includes students majoring in the performing arts.*** Clearly the future of science in America begins with elementary teachers. As Howard Voss informed the U. S. House of Representatives Committee on Science, 'Science in the schools is the other end of the pipeline that feeds scientists into professional societies. ***Elementary school science must be taught by people who have actually learned science by experience and inquiry and who have learned about pedagogy***. Studying science is not the same as studying about science by reading books or watching computer monitors do cool things.' ***Elementary education departments must be made to see the value of quality hands-on science courses for all elementary teachers.***"
(My *italics*.)

AAPT. 2001. American Association of Physics Teachers, "Physical Science Resource Center.". especially under "Resource Center" / "Physics Education Research"; < **http://www.psrc-online.org/** >.

AAPT. Undated. American Association of Physics Teachers, J.D. Garcia, Ruth Howes, Ken Krane, Heidi Mauk, Mary Beth Monroe, Ed Neuenschwander, Dan Schroeder, Dan Smith, Judith Tavel, Stamatis Vokos, " < **http://www.aapt.org/** >/"AAPT Planning for the Future"/"White Paper on Undergraduate Education": AAPT's goals in the undergraduate arena are:

To ensure that every person who holds either an associates degree or a bachelors degree understands the basics of physics and its methods and applications well enough to enter today's high tech workplace and to make informed decisions on personal issues and on societal and political issues.

To help all students who aspire to a career related to math, science, engineering, and technology ***to develop conceptual and quantitative problem-solving abilities as well as scientific reasoning skills.***

To help physics departments to recruit talented and diverse students as physics majors and ***provide them with the skills they need to enter the workforce or to pursue graduate studies in physics or other fields.***

To promote the recruitment and in-depth preparation of K-12 teachers who teach physics and physical science as a process of inquiry. *[This goal is so important to AAPT that it is treated in a separate white paper . . . .*(AAPT, Undated. John Hubisz, two pages above). . . .*]*

To be a catalyst for the systematic and sustainable improvement of physics instruction ***in ways that are informed by results from physics education research.*** (My *italics.*)

AAPT, APS, and AIP. 2000.* R.H. Howes & R.C. Hilborn, "Winds of Change," Am. J. Phys. 68(5), 401-402: " . . . . An undergraduate physics program is more than just the curriculum. The program includes the full spectrum of the departments activities, including its majors program, service courses, ***preparation of K-12 teachers***, and undergraduate research opportunities . . . . ***All meaningful change in undergraduate physics must be local. A "one size" program will not fit all.*** The new environment is unlikely to return to its state of thirty-some years ago. Thus, it is up to the physics community to respond creatively and constructively to the new environment. Those looking for a quick fix, however, are going to be disappointed. It will probably take sustained efforts on many fronts over the next ten years before we see substantial results from these efforts. To focus the undergraduate physics efforts and to provide advice to the physics community, AAPT, APS, and AIP have established a ***National Task Force on Undergraduate Physics.***"(NTFUP)* (My *italics.*)

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*In my opinion, the Howes/Hilborn "National Task Force on Undergraduate Physics" (NTFUP) should consider the work of its mathematics counterpart the Mathematics Association of America's "Committee on the Undergraduate Program in Mathematics" (CUPM)- see MAA (2000).

AASCU. 1991. American Association of State Colleges and Universities (advancing liberal learning for all students), "A Call for Teacher Education Reform: A Report of the AASCU Task Force on Teacher Education"; ordering information is at < **http://www.aacu-edu.org/Publications/ordering.html** >.

***ABET (Accreditation Board for Engineering and Technology),** 2000-2. < **http://www.abet.org/** >. "Engineering Criteria for 2000-2001 & 2001-2002"; < **http://www.abet.org/eac/eac.htm** >.

ACE. 1999. American Center for Education:

a. *To Touch the Future: Transforming the Way Teachers are Taught. An Action Agenda for College and University Presidents, 1999* < **http://www/acenet.edu/resources/presnet/** >.

b. D.P. Scannell, "Models of Teacher Education," 1999 < **http:www.acenet.edu/bookstore/#teacher-ed** >.

c. C. M. Frazier, *Quality Control and Quality Assurance Issues* (American Council on Education, 1999; < **http:www.acenet.edu/bookstore/#teacher-ed** >.

d. Linda-Darling Hammond & Barnett Berry, *Teacher Supply, Demand, and Quality*,1999. Soon to be online at < **http:www.acenet.edu/bookstore/#teacher-ed** >.

ACHIEVE. 2001. < **http://www.achieve.org/** >: "Achieve, Inc., is an independent, bipartisan, not-for-profit organization formed in 1996 by governors and corporate CEOs who shared a powerful belief that: *high academic standards, demanding tests to measure those standards, and accountability for performance can push our schools and students to much higher achievement.* Today, Achieve is working to make that vision a reality. Our innovative initiatives help states implement high-quality education reforms that will improve student performance." See especially under "About Achieve,": "1999 National Education Summit." and "Public Leadership." A good set of "Links" is available.

AFT. 1999. American Federation of Teachers; < **http://www.aft.org/** > " Making Standards Matter: Executive Summary; < **http://www.aft.org/edissues/standards99/** >

AFT. 2000. American Federation of Teachers; < **http://www.aft.org/** >; "Building a Profession: Strengthening Teacher Preparation and Induction," Report of the K-16 Teacher Education Task Force, 2000; < **http://www.aft.org/higher_ed/reports/K16report.html** >.

AIP, APS, AAPT, UNL. 2000. American Institute of Physics, American Physical Society, American Association of Physics Teachers, Univ. of Nebraska - Lincoln, NebraskaEPSCoR, Working Conference, "The Role of Physics Departments in Preparing K-12 Teachers," June 8 - 9, 2000. < **http://physics.unl.edu/~diandra/DLP/TeachersConference.html** > See under ""Reading Lists" for a good set of references on this subject. "The Challenge: Improving the scientific preparation of prospective K-12 teachers has received dramatically increased attention and support in the last eight years. State and regional accountability efforts have included the adoption of state science standards, often based on a small number of national models. These standards mandate science content knowledge, thorough understanding of the process and context of science and familiarity with technology as a tool for learning. States and local school systems are changing accreditation and hiring requirements in response to the new standards. ***There is a perception that the colleges and universities that prepare teachers are not adapting rapidly enough to prepare new teachers to meet the challenges that they will face.*** Teacher preparation has been identified as a federal priority in budget efforts of both Congress and the Executive Branch. There is a ***forecast need for two million new teachers within the next decade*** that will strain an already burdened system of teacher preparation. ***Professional societies of mathematicians and scientists have supported statements that encourage discipline-based departments to more vigorously and collaboratively engage in the process preparing future teachers, recognizing that all elementary school teachers are teachers of science and mathematics***." (My *italics*.)

***AIP, APS, AAPT, AAS, ASA, AAPM, AVS.** 1999. American Institute of Physics, American Physical Society, American Association of Physics Teachers, American Astronomical Society, Acoustical Society of America, American Association of Physicists in Medicine, American Vacuum Society. *Statement on the Education of Future Teachers*; < **http://www.aip.org/education/futeach.htm** >.

***APS.** 2000. *APS News Online*. 2000. "Site Visits To Identify Strong Candidates for New Education Program," October; < **http://www.aps.org/apsnews/1000/100001.html** >.

APS. 2001a. American Physical Society "Trilling Outlines Challenges, Priorities for APS in a Time of Change"; < **http://www.aps.org/apsnews/0101/010108.html** > : "Promoting the advancement and diffusion of the knowledge of physics includes trying to improve the quality of science education. Many members of our Society have personally involved themselves in this effort through classroom visits, participation in school boards, running in-service teacher workshops at their institutions etc. *The APS Education Department has recently focused on an ambitious program aimed at the improvement of elementary and secondary school science education, to respond to two major needs: i) developing enough motivated and well-prepared graduates of our school system to ensure an adequate supply of future scientists to maintain the health of our research effort, and ii) preparing the general public for a world in which science and technology are playing an increasingly important role.* ***The Education Dept. under Fred Stein, in collaboration with AAPT and AIP, is developing an ambitious new initiative to improve undergraduate college courses and curricula aimed specifically at future K-12 science teachers. . . .*** (See Sec. IIID on "PhysTEC".). . . ***If successful, this program may lead not only to better trained and motivated science teachers, but also may stimulate the broadening and modernization of the general undergraduate programs for physics majors.***" (My *italics*.)

APS. 2001b. American Physical Society, "Policy Statement on K-12 Science and Mathematics Education," < **http://www.aps.org/apsnews/0201/020101.html** >: "In an age of rapid technological advances, ***a strong educational program in science and mathematics is essential for the United States. Despite the heroic efforts of many teachers and the large investments of school districts, in too many places we currently fail to provide it.*** Too many citizens leave school without the scientific literacy necessary to deal with new technologies, and their far-reaching societal implications. . . . ***Particularly in the physical sciences, too many students receive instruction from teachers insecure in their subject area knowledge***. . . . To support a vision of science and mathematics education that ensures that all students receive high quality instruction, the APS recommends that policy makers:

Enhance support for the preparation of prospective science and mathematics teachers, particularly those programs that involve collaborative efforts of college or university departments of science and mathematics with their departments of education . . . .

Support sustained efforts to develop and implement high quality instructional materials for science and mathematics . . . .

Increase research on how students learn science and mathematics, and develop and disseminate strategies and conditions that promote effective teaching, learning and appropriate assessment." (My *italics*.)

ASU. Undated. Arizona State University, "A Working Proposal for a National Center for Physics Education (NCPE)" < **http://modeling.la.asu.edu/modeling.html** > / "National Center for Physics Education" (NCPE): "The National Science Education Standards . . . < **http://www.nap.edu/readingroom/books/nses/** > . . . pointedly avoid the issue of how to implement science education reform. The NCPE will fill that gap by creating a nationwide infrastructure that brings the full resources of the physics community to bear on the problems of shaping and implementing sustained K-12 science reform.. . .(With regard to pedagogical reform). . . ***.new evaluation instruments have documented serious deficiencies in conventional teaching methods as well as considerable improvements from research-based instructional designs. However, these advances have not yet been widely diffused or deeply assimilated by most physics teachers***. Deeper reforms in curriculum and instruction are continually emerging from educational research, but adequate mechanisms to move them into the classroom are still lacking. . . . . Ultimately, all reform takes place in the classroom. Therefore, ***the key to reform is to cultivate teacher expertise***. The vast majority of physics teachers are under-prepared, isolated, and overworked. However, they are also dedicated, able, excited about science, and hungering to learn more. Above all they need opportunities for professional growth and a supportive school environment. Lifelong professional development is as essential for teachers as it is for doctors. Typically, ***it takes at least ten years to reach a high level of expertise in any profession***. Few teachers have adequate opportunities for sustained professional development, and many have an inadequate background in science to start with, so most remain far from reaching their full potential as teachers. The NSES emphasizes that "coherent and integrated programs" supporting "lifelong professional development" of science teachers are essential for significant reform. They state that "***The conventional view of professional development for teachers needs to shift from technical training for specific skills to opportunities for intellectual professional growth." Such a program cannot be consistently maintained and enriched in any locality without dedicated support from a local university."*** (Local Physics Alliances, University Partners, and School District Partners are suggested.) (My *italics*.)

CASTL. Undated. Carnegie Academy for the Scholarship of Teaching and Learning < **http://www.carnegiefoundation.org/CASTL/** >
"\. . . . represents a major initiative of The Carnegie Foundation for the Advancement of Teaching. Launched in 1998, the program builds on a conception of teaching as scholarly work proposed in the 1990 report, *Scholarship Reconsidered*, by former Carnegie Foundation President Ernest Boyer . . .Boyer (1990). . . ., and on the 1997 follow-up publication, *Scholarship Assessed*, by Charles Glassick, Mary Taylor Huber, and Gene Maerof." . . . .Glassick, Huber & Maerof (1997). . .

(a) Boyer Commission. 1998. "Reinventing undergraduate education: A blueprint for America's research universities." The Boyer Commission on Educating Undergraduates in the Research University < **http://notes.cc.sunysb.edu/Pres/boyer.nsf** >:"The university's essential and irreplaceable function has always been the exploration of knowledge. **This report insists that the exploration must go on through what has been considered the 'teaching' function as well as the traditional 'research' function.** The reward structures in the modern research university need to reflect the synergy of teaching and research - and the essential reality of university life: that baccalaureate students are the university's economic life blood and are increasingly self-aware." (My *italics.*)

(b) *Journal of Scholarship of Teaching and Learning* < **http://www.iusb.edu/%7Ejosotl/** >.

(c) Programs for K-12 < **http://www.carnegiefoundation.org/CASTL/k-12/index.htm** >:

(d) Programs for Higher Education < **http://www.carnegiefoundation.org/CASTL/highered/index.htm** >: The following references are hot linked:

"Approaching the Scholarship of Teaching and Learning" by Pat Hutchings. Introduction to *Opening Lines: Approaches to the Scholarship of Teaching and Learning*

"Inventing the Future" by Lee S. Shulman. Conclusion to *Opening Lines: Approaches to the Scholarship of Teaching and Learning*

"The Scholarship of Teaching: New Elaborations, New Developments" by Pat Hutchings and Lee S. Shulman. Originally published in the September/October 1999 issue of *Change.*

"Disciplinary Styles in the Scholarship of Teaching and Learning by Mary Taylor Huber. Presented at the 7th International Improving Student Learning Symposium, September 1999.

"The Scholarship of Teaching: What's the Problem?" by Randy Bass. Published in the online journal *Inventio* at George Mason University.

"The Scholarship of Teaching by Eileen Bender and Donald Gray. The introduction published in a special issue of the Indiana University journal, *Research and Creative Activity.*

"Visions of the Possible: Models for Campus support of the Scholarship of Teaching and Learning," by Lee S. Shulman. Based on comments made at meetings during November and December, 1999, bringing together research university faculty and administrators interested in the advancement of teaching and the scholarship of teaching.

"From Minsk to Pinsk: Why A Scholarship of Teaching and Learning," by Lee S. Shulman. Published in the first issue of *The Journal of Scholarship of Teaching and Learning (JoSoTL)*, and based on a presentation to the AAHE) at its 2000 annual meeting in Anaheim, CA

"An Annotated Bibliography of the Scholarship of Teaching and Learning in Higher Education," compiled by Pat Hutchings and Chris Bjork. [***For a much more complete annotated bibliography see Nelson (2000)***].

Core Knowledge. 2001. < **http://www.coreknowledge.org/** >. "Dedicated to excellence and fairness in early education, the Core Knowledge Foundation is an independent, non-profit, non-partisan organization founded in 1986 by E. D. Hirsch, Jr., a professor at the University of Virginia and author of many acclaimed books including *Cultural Literacy: What Every American Needs to Know* and *The Schools We Need and Why We Don't Have Them..* . [Hirsch (1996)]. . .The foundation conducts research on curricula, develops books and other materials for parents and teachers, offers workshops for teachers, and serves as the hub of a growing network of Core Knowledge schools."

CSBE. 1998. California State Board of Education, "K-12 Science Standards," (Adopted 10/98) < **http://www.cde.ca.gov/board/** >; "K-12 Science Standards" (Draft of 7/2000) < **http://www.cde.ca.gov/cilbranch/cfir/drscfw.pdf** >.

ECS. Undated. Education Commission of the States ("helping state leaders shape education policy") < **http://www.ecs.org/** >. See especially under "Education Issues" and "Links" to Federal Agencies, Regional Education Labs, National Organizations, Research Centers and Organizations, States and Territories, and Media. See also "Two Paths to Quality Teaching: Implications for Policymakers," an ECS Staff Comparison of the Positions of the *National Commission on Teaching and America's Future* (NCTAF) < **http://www.nctaf.org/** > and the *Thomas B. Fordham Foundation* (TBFF) < **http://www.edexcellence.net/index.html** >. Based on a debate between Linda Darling-Hammond (NCTAF) and Chester E. Finn, Jr. (TBFF) at the Spring Steering Committee Meeting of the ECS, March 26, 2000, Cheyenne, Wyoming. Revised June, 2000; < **http://www.ecs.org/clearinghouse/12/22/1222.htm** >.

Education Trust. 2000. ("Works for the high academic achievement of all students at all levels, kindergarten through college. Our basic tenet is this — all children will learn at high levels when they are taught to high levels.") < **http://www.edtrust.org/main/index.asp** > . See especially under "Reports and Publications":

a. *"Honor in the Boxcar: Equalizing Teacher Quality" in *Thinking K-16*, Spring 2000; < **http://www.edtrust.org/main/reports.asp** >.

b. Kati Haycock, "Good Teaching Matters: How Well-Qualified Teachers Can Close the Gap" in *Thinking K-16*, Summer 1998; < **http://www.edtrust.org/main/reports.asp** >.

c. Kati Haycock, "The Role of Higher Education in the Standards Movement" in *1999 National Education Summit Briefing Book*; < **http://www.achieve.org** > see also at < **http://www.edtrust.org/** >: "Higher education.... (unlike Governors and CEO's) ..... Has been left out of the loop and off the hook .... (in the effort to improve America's public schools since release of A Nation at Risk in 1983).... Present neither at the policy tables where improvement strategies are formulated nor on the ground where they are being put into place, ***most college and university leaders remain blithely ignorant of the roles their institutions play in helping K-12 schools get better - and the roles they currently play in maintaining the status quo*** .... *How are we going to get our students to meet high standards* ***if higher education continues to produce teachers who don't even meet those same standards?*** How are we going to get our high school students to work hard to meet new, higher standards if most colleges and universities will continue to admit them regardless of whether or not they even crack a book in high school?" (My *italics*.)

MAA. 2001. Mathematics Association of America, "The MAA's CUPM Pushes Curriculum Initiative" < **http://www.maa.org/news/cupm.html** > : "The Committee on the Undergraduate Program in Mathematics (CUPM) kicked off a major curriculum initiative during the recent Mathfest in Providence. ***CUPM has determined that their curriculum initiative will focus on what students should know and experience as they complete their mathematics requirements, including the types of problems students should be able to solve, the technology students should be able to utilize, and the mathematical and process skills that students should have.*" (My *italics*.)

Mathematics and the Mathematical Sciences in 2010: What Should Students Know? < **http://www.maa.org/news/cupm_text.html** >: "**A Special Responsibility to Future Teachers**. How often have you met someone casually, explained that you 'do mathematics,' and heard in reply, 'Math, I could never do that'? Our first lines of defense against such illiteracy are the teachers in our schools. The country is encountering critical shortages of mathematics and science teachers. Not only do we want high quality teachers who love mathematics, but we want those teachers to teach as we want our children to learn. While many universities assume as their primary responsibility the preparation of future teachers, other universities also have mathematics students who contemplate becoming teachers. ***Every department should discuss the role of its program in the preparation of future teachers of mathematics and science*.**" (My *italics*.)

Conference Board of the Mathematical Sciences, *Mathematical Education of Teachers* (in preparation). < **http://www.maa.org/metdraft/index.htm** >: "Two general themes that guide this report are: (i) the intellectual substance in school mathematics; and (ii) the special nature of the mathematical knowledge needed for teaching. There has been a widespread assumption that because the topics covered in school mathematics are so basic, they must also be easy to learn and to teach. ***We owe to mathematics education research of the past decade or so the realization that substantial mathematical understanding is needed even to teach even whole number arithmetic well.*** ‡ Several mathematics educators, especially Deborah Ball . . [Ball & Bass (2000)] . . and Liping Ma . . [Ma (1999)] . . have been able to communicate these findings in a way that engaged research mathematicians. The structure of the rational numbers and the idea of proportionality, as two examples, make even greater demands for teaching the middle grade curriculum well. While the mathematical substance of the high school curriculum is widely acknowledged, the challenges in developing a deep understanding of it have not been. . . . . ***The mathematical knowledge needed for teaching is quite different from that required by college students pursuing other math-related professions.**** Prospective teachers need to learn how fundamental mathematical principles underlie classroom practice, so that they can teach mathematics as a coherent, reasoned activity and communicate an appreciation of the elegance and power of the subject. ***It is vital for mathematical faculty to play the leading role in instruction in the mathematical knowledge needed for teaching.*** To be effective, this instruction needs to involve a collaboration between mathematicians and mathematics educators and to be connected closely to classroom practice. This report is not geared to any particular curriculum for school mathematics, although it is compatible with the 2000 *NCTM Principles and Standards for School Mathematics* . . NCTM (2000) . . . as well as other recent national reports on school mathematics." (My *italics*.)

* Analogous statements apply to physics. In addition to content knowledge, teachers must also possess "pedagogical content knowledge" a term evidently coined by L.S. Shulman (1986/87) and discussed with regard to physics education by Hake (2001a).

Mathemetically Correct. 2001. < **http://ourworld.compuserve.com/homepages/mathman/** >, especially the "Science Corner" at < **http://mathematicallycorrect.com/science.htm** >. This "back to basics" group played an influential role in the adoption of the current California math and science standards. [See Becker & Jacob (2000), Finn & Petrilli at TBFF (2001), Feder (1998).]

NAAL . 2001. National Academy for Academic Leadership. Mission. < **http://www.TheNationalAcademy.org/** >
" . . . . . educates academic decision makers to be leaders for sustained, integrated institutional change that significantly improves student learning. ***Its curriculum is based on research and best practices.*** Its programs are designed both for institutional teams working on campus projects and for individuals--presidents, board members, vice presidents, deans, chairs and key faculty members--with role-specific responsibilities and concerns. The National Academy recognizes the considerable variation among institutions in their readiness for change and their resources for leadership development, and so programs are geared to the unique institutional contexts and specific needs of participants." (My *italics*.)

National Academies. 2001. "Advisers to the Nation on Science, Engineering, and Medicine" < **http://www.national-academies.org/** >.
(a) Center for Education < **http://www4.nationalacademies.org/cfe/cfe.nsf** >: "The 'Center for Education' of the *National Academies*, formed in 2000 and incorporating the Center for Science, Mathematics, and Engineering Education and the Board on Testing and Assessment, is ideally situated to initiate programs that make a real difference in American education. By engaging the unique strength of the *National Academies* to bring together national, state, and local leaders from education, academia, industry, government, and other sectors, the Center is poised to address critical national issues in education research, policy, and practice.
Common visions for educational reform in science, mathematics, and engineering education--set forth in documents such as the *National Science Education Standards* . . . NRC (1996b). . ., the National Council of Teachers of Mathematics' (NCTM) *Curriculum and Evaluation Standards for School Mathematics*. . .(NCTM (2000) . . ., and *From Analysis to Action* . . . NRC (1996a). . . which reports on undergraduate science, mathematics, and technology education--provide frameworks within which all those involved in the reform of education nationwide can achieve success. Research perspectives on the roles of testing, assessment, and evaluation also contribute across the work of the Center." (See also NRC (1997, 1999) and "National Research Council" in the "Books" reference section.)

(b) National Academy Press < **http://www.nap.edu/** > "the most powerful website research engine" is available to search for key words in NAP titles, all text, and categories.

NCEI. 2001. National Center for Educational Information; < **http://www.ncei.com/** >"..A private, non-partisan research organization in Washington, D.C. specializing in survey research and data analysis. NCEI is the authoritative source of information about alternative teacher preparation and certification."

NCES. 1996. National Center for Educational Statistics, National Assessment of Educational Progress (NAEP); *The Nation's Report Card*, on the web at < **http://nces.ed.gov/nationsreportcard/site/home.asp** >. C. Y. O'Sullivan, C. M. Reese, and J. Mazzeo NAEP 1996 Science: Report Card for the Nation and the States, on the web at < **http://nces.ed.gov/nationsreportcard/96report/97497.shtml** >: "Three percent of the nation's students reached the Advanced level at all three grade levels. Twenty-six percent of fourth- and eighth-grade students and 18 percent of the twelfth-grade students performed within the Proficient level, while 38 percent, 32 percent, and 36 percent performed within the Basic level for grades 4, 8, and 12, respectively." Paul Gross [see under TBFF (2001), in "Politicizing Science Education,"] states that "in the Massachusetts assessment system, the category matching NAEP's 'Basic' is called 'Needs Improvement.' That is much more honest.")

NCTAF. Undated. National Commission on Teaching and America's Future < **http://www.nctaf.org/** >. See especially the sections on "Policy and Practice," and "What Matters Most: Teaching for America's Future" < **http://www.nctaf.org/publications/whatmattersmost.html** >.

NCTAF Recommendations:

1. Get serious about standards for both students and teachers.
2. <u>Reinvent teacher preparation and professional development</u>:
   a. *Organize teacher education and professional development around standards for students and teachers.*
   b. *Institute extended, graduate-level teacher preparation programs that provide year-long internships in a professional development school.*
   c. *Create and fund mentoring programs for beginning teachers that provide support and assess teaching skills.*
   d. *Create stable, high-quality sources of professional development; then allocate one percent of state and local spending to support them, along with additional matching funds to school districts.*
   e. *Embed professional development in teachers' daily work through joint planning, study groups, peer coaching, and research.*
3. Overhaul teacher recruitment and put qualified teachers in every classroom.
4. Encourage and reward knowledge and skill.
5. Create schools that are organized for student and teacher success

NCTM. 2000. National Council of Teachers of Mathematics, *Principles and Standards for School Mathematics*; < **http://standards.nctm.org/** > and < **http://standards.nctm.org/document/index.htm** >.

NEA. 2001. National Education Association - teachers' union < **http://www.nea.org/** >. Under "Teaching" < **http://www.nea.org/teaching/** > see "NEA Fact Sheet,. "Ready or Not: A National Teacher Shortage Looms," < **http://www.nea.org/teaching/shortage.html** >: "***Nationwide, some 2.4 million teachers will be needed in the next 11 years because of teacher attrition and retirement and increased student enrollment.***" (Source: National Center for Education Statistics.)

NISE. 2001. National Institute for Science Education < **http://www.wcer.wisc.edu/NISE/** >, "Field-tested Learning Assessment Guide: For Science, Math, and Engineering Instructors" < **http://www.wcer.wisc.edu/nise/cl1/flag/flaghome.asp** >, esp. "Introduction to CAT's" (Classroom Assessment Techniques) at < **http://www.wcer.wisc.edu/nise/cl1/flag/cat/catframe.asp** >.

NRC. 1996a. National Research Council. *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology; Report of a Convocation* (National Academy Press); < **http://books.nap.edu/catalog/9128.html** >.

NRC. 1996b. National Research Council. *National Science Education Standards* (Nat. Acad. Press); < **http://books.nap.edu/catalog/4962.html** >

NRC. 1997. National Research Council. All from the National Academy Press:
(a) *Challenges Facing a Changing Society* < **http://books.nap.edu/catalog/9534.html** >,
(b) *Preparing for the 21st Century: The Education Imperative* < **http://books.nap.edu/catalog/9537.html** >,
(c) *Science and Engineering Research in a Changing World* < **http://books.nap.edu/catalog/9539.html** >,
(d) *Technology and the Nation's Future* < **http://books.nap.edu/catalog/9535.html** >,
(e) *The Environment and the Human Future* < **http://books.nap.edu/catalog/9536.html** >,
(f) *Focussing on Quality in a Changing Health Care System.* < **http://books.nap.edu/catalog/9538.html** >.

NRC. 1999. National Research Council, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Academy Press); < **http://books.nap.edu/catalog/6453.htm** >.

***NSF.** 1996. National Science Foundation.. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by Melvin George,); < **http://www.nsf.gov/cgi-bin/getpub?nsf96139** >.

NSF. 1998. National Science Foundation. *Shaping the Future, Volume II: Perspectives on Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by James M. Rosser, 1998) < **http://www.nsf.gov/cgi-bin/getpub?nsf98128** >. Contains an extensive bibliography on SME&T undergraduate education that, unfortunately, omits most of the relevant physics literature.

NSF. 1998. National Science Foundation. *Science and Engineering Indicators*, esp. Chap. 7, "Science and Technology"; < **http://www.nsf.gov/sbe/srs/seind98/start.htm** >. "..... despite substantial media attention to deep space probes and pictures from the Hubble Space Telescope, *only 48 percent of Americans know that the earth goes around the sun once each year.....* ***Only 27 percent of Americans understand the nature of scientific inquiry well enough to be able to make informed judgments about the scientific basis of results reported in the media.*** Public understanding of the nature of scientific inquiry was measured through questions about the meaning of scientific study and the reasons for the use of control groups in experiments." (My *italics*.)

Nuffield Foundation. 1999. *Beyond 2000 - science education for the future* (Nuffield Foundation, UK) - produced by a group of prominent UK science educators, makes 10 major recommendations for the future direction of science education, at
< **http://www.kcl.ac.uk/depsta/education/be2000/index.html** >.

Phi Delta Kappa. 2001. < **http://www.pdkintl.org/** > "An international association for *professional educators.* The organization's mission is to promote quality education, with particular emphasis on publicly supported education, as essential to the development and maintenance of a democratic way of life."
Phi Delta Kappan ("The Professional Journal of Education") < **http://www.pdkintl.org/kappan/kappan.htm** >.
Articles online: < **http://www.pdkintl.org/kappan/karticle.htm** >.

PKAL. 2001. Project Kaleidoscope < **http://www.pkal.org/** >, especially:
"K-16 Connections" < **http://www.pkal.org/curricul/k16/index.html** >.
Bruce Alberts, President of the National Academy of Sciences, "Redefining the Scientific Community,"
< **http://www.hhmi.org/grants/undergraduate/meetings/1997/keynote.htm** >.
F.G. Rothman &, J.L. Narum, *Then, Now, & In the Next Decade: A Commentary on Strengthening Undergraduate Science, Mathematics, Engineering and Technology Education.*, January 2000; < **http://www.pkal.org/pubs/index.html** >.

Reinvention Center, Stony Brook. 2000. ". . . new national center focusing on undergraduate education at research universities.
< **http://www.sunysb.edu/provost/Programs/Reinvent/** >: Goals: "Promote an expanded view of undergraduate education that encompasses a change in the current norms and expectations for baccalaureate study. Track research findings and 'best practices' and communicate them to appropriate constituents with the goal of stimulating further discussion and action."

TBFF. 2001. Thomas B. Fordham Foundation ("Advancing sound research and fresh ideas on K-12 education reform". . .(from a usually moderately conservative standpoint) < **http://www.edexcellence.net/index.html** >:
"The Teachers We Need and How to Get More of Them: A Manifesto" < **http://www.edexcellence.net/better/tchrs/06.htm** > endorsed by "governors, chief state school officers, state board members, prominent education thinkers and analysts, and veteran practitioners, which sets forth principles and policies to guide states as they prepare to hire a teaching force for the 21st century." Among the signatories are William J. Bennett (1994)), Denis Doyle (Doyle & Pimentel (1999)], Chester Finn (see below), Paul Gross [see below and Gross & Levitt (1994)], E.D. Hirsch (1996), Diane Ravitch (2000) , and Lynne Reder [Anderson, Reder, & Simon (1998)].

C. E. Finn, B. V. Manno, and D. Ravitch; with K. Amis, M. Kanstoroom and M. J. Petrilli, "Education 2001: Getting the Job Done (A memorandum to the President-Elect and the 107th Congress)" < **http://www.edexcellence.net/education_2001.html** >.

TBFF. 2001. Thomas B.Fordham Foundation (continued)

P.R. Gross,"Politicizing Science Education," < **http://www.edexcellence.net/library/gross.html** >. In my opinion, Gross's discussions of the anti-evolution movement and the need for improvement of science education are on target, but his near blanket condemnation of "constructivism" is inconsistent with the results of physics-education research of the past two decades. The latter demonstrates the relative effectiveness of constructivist-oriented educational strategies such as "interactive engagement." (See e.g., Sec. VB on FCI pre/post testing.)

C.E. Finn & M.J. Petrilli, "The State of the State Standards 2000" (SOSS2000), < **http://www.edexcellence.net/fordham/foreports.html#anchorStds** > , a 7.8 MB pdf version is available. But see the criticism of SOSS2000 by G.W. Bracey "A review of 'The State of State Standards' " at < **http://www.uwm.edu/Dept/CERAI/edpolicyproject/cerai-00-07.htm** >.

The evaluation of science standards was directed by Lawrence Lerner, an Emeritus Professor in the College of Natural Sciences and Mathematics at California State University, Long Beach. SOSS2000 places California FIRST (with an A) among all the states in the quality of State Science Standards. According to SOSS2000: "Overall, the document. . .[1998 Science Content Standards, Grades K-12, CSBE (1998)]. . . .is superbly done. It is scientifically correct, written in clear language, and well organized. . . . The physical sciences are dealt with carefully and systematically. In the upper grades, the fact that these sciences are essentially quantitative is made explicit. . . . ***All in all, California now boasts one of the best science standards presently available.***"

In stark contrast, a *Science Education Petition* of 22 December 1999 < **http://www.sci-ed-ga.org/standards/petition.html** >, circulated by Larry Woolf of General Atomics states that the California Science Standards: "are based on neither the spirit nor the letter of the National Science Education Standards developed by the National Academy of Sciences . . .[National Research Council (1996)]. . . or the Benchmarks for Science Literacy. . .[AAAS 1993). . . .developed by the American Association for the Advancement of Science; ***are incorrect, misleading, ambiguous, and age-inappropriate."*** The petition further states that ***"California Academic Standards Commission has approved a policy that effectively prohibits the adoption of scientifically accurate, thoroughly tested, and highly regarded kit-based science curricula,. . . .(and) . . . has approved a policy that allows the adoption of materials that have never been thoroughly tested in classrooms."*** (My *italics*.)

Woolf's petition is signed by 330 Californians, among them: Andrew Sessler, past President of the APS; James Langer, current president of the APS; Jerry Pine, co-director of the Cal Tech Precollege Science Institute; Wendell Potter, vice chair of the Physics Dept., Univ. of California at Davis; Helen Quinn of the Stanford Linear Accelerator; Richard Shavelsohn, Professor of Education and Psychology at Stanford; J.M. Atkin, Chair of the Committee on Science Education K-12 at the National Research Council; Fred Goldberg, Professor of Physics, San Diego State University; Angelica Stacy, Professor of Chemistry, Univ. of California-Berkeley; and many California science teachers and educators from elementary, middle, and high schools; colleges; and universities. For some commentary on the "California Science Standards War" see T. Feder (1998).

U.S. Commission on National Security -Hart Rudman Commission (USCNS), "Road Map for National Security: Imperative for Change"; Phase III Report of the U.S. Commission on National Security/21st Century < **http://www.nssg.gov/** >: "The harsh fact is that ***the U.S. need for the highest quality human capital in science, mathematics, and engineering is not being met.*** (Their *italics.*) One reason for this is clear: American students know that professional careers in basic science and mathematics require considerable preparation and effort, while salaries are often more lucrative in areas requiring less demanding training. Non-U.S. nationals, however, do find these professions attractive and, thanks to science, math, and technical preparation superior to that of many Americans, they increasingly fill American university graduate studies seats and job slots in these areas. ***Another reason for the growing deficit in high-quality human capital is that the American kindergarten through 12 th grade (K-12) education system is not performing as well as it should. As a result too few American students are qualified to take these slots, even were they so inclined.*** (My *italics.*) . . . . . We also recommend a new National Security Science and Technology Education Act to fund a comprehensive program to produce the needed numbers of science and engineering professionals as well as qualified teachers in science and math. This Act should provide loan forgiveness incentives to attract those who have graduated and scholarships for those still in school and should provide these incentives in exchange for a period of K-12 teaching in science and math, or of military or government service. Additional measures should provide resources to modernize laboratories in science education, and expand existing programs aimed at helping economically-depressed school districts."

U. S. Congress, *Unlocking Our Future: Toward a New National Science Policy*, A Report to Congress by the committee on Science chaired by Vernon Ehlers, 9/24/98 at < **http://www.house.gov/science/education.htm** > : "Currently, the U.S. spends approximately $300 billion a year on education and less than 30 million, 0.01% of the overall education budget, on education research. At a time when technology promises to revolutionize both teaching and learning, this miniscule investment suggests a feeble long-term commitment to improving our educational system." The provisions of the three Ehlers Bills are described in the AIP "FYI" of 4/17/00 at < **http://www.aip.org/enews/fyi/2000/fyi00.041.htm** >. See also the news reports by:

(a)**R.M. Torado.** 2001. "Ehlers to Reintroduce Controversial Science Education Bill" *APS News*, February 2001, < **http://www.aps.org/apsnews/0201/020108.html** > "When the House of Representatives surprised even itself last October and voted down a popular bill to provide money and personnel for elementary and middle school science and math education, it represented a stunning display of the power of the country's largest teachers' unions. ***The defeat also set the stage for a further escalation in the battle over school vouchers, with the bill's chief architect, Rep. Vernon J. Ehlers (R-MI), vowing to reintroduce the bill in the first session of the new 107th Congress.*** Ehlers is one of two members of the House who hold PhD's in physics . . .the other is Rush Holt (D-NJ). . . . , and is a Fellow of the APS. Introduced by Ehlers in April 2000, the National Science Education Act (NSEA) had 16 original co-sponsors, a number that grew to include 62 Republicans and 45 Democrats by the time it was brought out of committee and to the full House in September. So confident were its sponsors of overwhelming, bipartisan passage that the bill was fast-tracked under so-called suspension of the rules, meaning the bill had to get a two-thirds majority. ***But on October 23rd, just one day before the scheduled vote, the National Education Association (NEA)*** . . .[see NEA (2001)] . . , ***the American Association of School Administrators, and several other influential teachers unions discovered a funding provision in the bill that they consider to be unacceptable. This was the so-called "master teacher" provision that directed the National Science Foundation to make federal money available to any schools, public or private, to hire someone to oversee the development of science education classroom curricula.*** " (My *italics*.)

(b) ***Glenn Commission.** 2000. *Before It's Too Late: A Report to the National Commission on Mathematics and Science Teaching for the 21st Century*; online at < **http://www.ed.gov/americacounts/glenn/toc.html** >. See also "Glenn Commission Report," *APS Forum on Education Newsletter*, Fall 2000, on the web at < **http://www.aps.org/units/fed/fall2000/index.html** >.
< **http://www.aps.org/apsnews/0201/020108.html** >

(c) **Leath, A.T.** 2001. FYI #17 - K-12 Education," 2/16 < http://www.aip.org/enews/fyi/2001/017.html >::
"Added to the mix are several smaller bills targeted specifically to improving science and math education. ***Reps. Rush Holt (D-NJ) and Connie Morella (R-MD) have proposed legislation (H.R. 117) incorporating many of the Glenn Commission's recommendations*** . . . . [see Glenn Commission (2000) . . .***including authorizing 15 Glenn Academies to provide summer professional development workshops and year-long Fellowships for prospective teachers. Rep. Vern Ehlers (R-MI) has reintroduced his trio of science education bills from last year*** (now H.R. 100, 101, and 102; see FYI's #39, 41, and 130, 2000), which would enhance science education programs at NSF and the Education Department and provide tax breaks for teachers' college tuition and industry contributions to science education. ***Sen. Pat Roberts (R-KS) plans to reintroduce companion legislation*** in the Senate; at yesterday's hearing he called improving science and math education for U.S. students 'a matter of national security.' Several other committee members also mentioned the importance of science and math education, with ***Chairman James Jeffords (R-VT) urging greater collaboration between colleges of education and science and math departments to improve teacher preparation, curricula, and educational research in those disciplines***. . . . .It is important to keep in mind that all of the legislative efforts mentioned above are authorization, and not appropriations, bills. Authorization bills are intended to set policy and spending guidelines, but do not provide the actual money. How well any of these efforts fare, even if they are passed, depends on whether they are funded adequately in the relevant appropriations bill. (My *italics*.)

U.S. Department of Education, National Research & Development Centers. 2000 < **http://www.ed.gov/offices/OERI/ResCtr.html** >
Mission: "To address nationally significant problems and issues in education, the U.S. Department of Education's Office of Educational Research and Improvement, through its five National Institutes, ***supports university-based national educational research and development centers***. The centers address specific topics such as early childhood development and learning, student learning and achievement , cultural and linguistic diversity and second language learning, postsecondary improvement, adult learning, and education policy. In addition, each center has collaborating partners, and many work with elementary and secondary schools as well as postsecondary institutions;" (My *italics*.)

U.S. Office of Educational Research and Improvement (OERI). Undated. < **http://www.ed.gov/offices/OERI/** > Under "Assistant Secretary's Message" is stated that: "***This office has lead responsibility for expanding the Nation's fundamental knowledge and understanding of education through research and development.*** We also support efforts to apply and test findings from research in classrooms, schools, college campuses and other educational settings. Through our many contractors and grantees, we provide research results to the public, policymakers, professional educators and a variety of organizations to enhance understanding of education and contribute to improvement efforts. Our National Center for Education Statistics (NCES) collects and analyzes data that are related to education in the United States and other nations." (My *italics*.)

U.S. Office of Educational Research and Improvement (OERI). Undated. Educational Resources Information Center (ERIC) and Other Clearinghouses: < **http://www.ed.gov/EdRes/EdFed/ERIC.html** > "The Educational Resources Information Center (ERIC), funded by OERI, is a nationwide information network that acquires, catalogs, summarizes, and provides access to education information from all sources. The data base and ERIC document collections are housed in about 3,000 locations worldwide, including most major public and university library systems. ERIC produces a variety of publications and provides extensive user assistance, including Ask ERIC, an electronic question answering service for teachers on the Internet. The ERIC system includes 16 subject-specific Clearinghouses, the ERIC Processing and Reference facility, and ACCESS ERIC which provides introductory services."
ERIC has a rather complex structure - my experience suggests that searches are best done at "h" and "i" below:

a. Introduction < **http://www.accesseric.org:81/** >
b. Site Map < **http://www.accesseric.org:81/sitemap/sitemap.html** >
c. Digests < **http://www.ed.gov/databases/ERIC_Digests/index/** >
d. List of Sites < **http://www.accesseric.org:81/sites/barak.html** >
e. Links to various ERIC Searches < **http://www.accesseric.org:81/searchdb/searchdb.html** >
f. Clearing House for Higher Education < **http://www.eriche.org/** >
g. Clearing House for Science, Mathematics, and Environmental Education < **http://www.ericse.org/** >
h. Clearing House for Assessment and Evaluation < **http://ericae.net/** >
    Search ERIC from ERIC/AE (articles back to 1990, the "more references like this" or "find similar" search is especially valuable) < **http://www.ericae.net/aesearch.htm** >
i. Clearing House for Information and Technology < **http://ericir.syr.edu/ithome/** >
    Search ERIC from ERIC/IT - called "AskEric" (articles from 1966 to 1/00) < **http://ericir.syr.edu/Eric/** >

Unfortunately, the ERIC data base fails to to include many crucial physics articles, see, e.g., S.P. Bowen, "ERIC databases do not contain Physics Education Research References over the last many years," AJP Forum on Education Newsletter, Summer 1999, p. 6; < **http://webs.csu.edu/~bisb2/FEdnl/eric.htm** >.

2. Articles

Anderson, J.R., L.M. Reder, and H. A. Simon. 1998. "Radical Constructivism and Cognitive Psychology" in *Brookings Papers on Education Policy - 1998*, Diane Ravitch, ed. (Brookings Institution Press), pp. 227-278. {Includes supporting comments by K. Andres Ericsson [Ericsson & Smith (1991)] and Robert Glaser.} Anderson *et al.* write: "The time has come to abandon philosophies of education and turn to a science of education.....If progress is to be made to a more scientific approach, traditional philosophies will be found to be like the doctrines of folk medicine. They contain some elements of truth and some elements of misinformation. This is true of the radical constructivist approach. ***Only when a science of education develops that sorts truth from fancy - as it is beginning to develop now will dramatic improvements in educational practice be seen."*** (My *italics.*)

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Becker, J.P. and B. Jacob. 2000. "The Politics of California School Mathematics: The Anti-Reform of 1997-99,"*Phi Delta Kappan*, March; < **http://www.pdkintl.org/kappan/kbec0003.htm** >. "The authors tell the story of a powerful group of parents and mathematicians in California who manipulated information and played off of the public's perception of our "failing schools" to acquire political clout. Through this telling, they hope that other states will be able to adopt a more rational course as they reconsider their policies."

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Bernhard, J. 1999. "How long-lived is post-course understanding of mechanics concepts?" submitted to *Phys. Teach*; < **http://www.du.se/~jbe/fou/didaktik/papers/fixed.html** >.

Black, P. & D. Wiliam. 1998. "Inside the Black Box: Raising Standards Through Classroom Assessment. *Phi Delta Kappan*, October; < **http://www.pdkintl.org/kappan/kbla9810.htm** >: "Firm evidence shows that formative assessment is an essential component of classroom work and that its development can raise standards of achievement, Mr. Black and Mr. Wiliam point out. Indeed, they know of no other way of raising standards for which such a strong prima facie case can be made."

Bloom, B.S. 1984. "The 2 sigma problem: the search for methods of group instruction as effective as one-to- on tutoring." *Educational Researcher* **13**(6), 4-16: "Using the standard deviation (sigma) of the control (conventional) class, it was typically found that the average student under tutoring was about two standard deviations above the average of the control class....The tutoring process demonstrates that most of the students do have the potential to reach this high level of learning. ***I believe an important task of research and instruction is to seek ways of accomplishing this under more practical and realistic conditions than the one-to-one tutoring, which is too costly for most societies to bear on a large scale. This is the '2 sigma' problem.*" (My *italics*.)

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Good Practice:

(1) Encourages Contacts Between Students and Faculty
(2) Develops Reciprocity and Cooperation Among Students,
(3) Uses Active Learning Techniques,
(4) Gives Prompt Feedback,
(5) Emphasizes Time on Task,
(6) Communicates High Expectations,
(7) Respects Diverse Talents and Ways of Learning.

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(b) Biology Teacher's Web Sites,
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The Ten Common Principles Of the Coalition of Essential Schools are:

1. ***The school should focus on helping young people learn to use their minds well*** . . . .. The school's goals should be simple: that each student master a limited number of essential skills and areas of knowledge. While these skills and areas will, to varying degrees, reflect the traditional academic disciplines, the program's design should be shaped by the intellectual and imaginative powers and competencies that the students need.. .. ***The aphorism "less is more" should dominate: curricular decisions should be guided by the aim of thorough student mastery and achievement rather than by an effort to merely cover content.***

3. ***The school's goals should apply to all students,*** while the means to these goals will vary as those students themselves vary. School practice should be tailor-made to meet the needs of every group or class of students.

4. Teaching and learning should be personalized to the maximum feasible extent. ***Efforts should be directed toward a goal that no teacher have direct responsibility for more than 80 students in the high school and middle school and no more than 20 in the elementary school.*** To capitalize on this personalization, decisions about the details of the course of study, the use of students' and teachers' time and the choice of teaching materials and specific pedagogies must be unreservedly placed in the hands of the principal and staff.

5. ***The governing practical metaphor of the school should be student-as-worker***, rather than the more familiar metaphor of teacher-as-deliverer-of-instructional-services. ***Accordingly, a prominent pedagogy will be coaching, to provoke students to learn how to learn and thus to teach themselves.***

6. ***Teaching and learning should be documented and assessed with tools based on student performance of real tasks.*** Students not yet at appropriate levels of competence should be provided intensive support and resources to assist them quickly to meet those standards. Multiple forms of evidence, ranging from ongoing observation of the learner to completion of specific projects, should be used to better understand the learner's strengths and needs, and to plan for further assistance. Students should have opportunities to exhibit their expertise before family and community. ***The diploma should be awarded upon a successful final demonstration of mastery for graduation - an "Exhibition." As the diploma is awarded when earned, the school's program proceeds with no strict age grading and with no system of credits earned" by "time spent" in class. The emphasis is on the students' demonstration that they can do important things.***

7. ***The tone of the school should explicitly and self-consciously stress values of unanxious expectation*** ("I won't threaten you but I expect much of you"), of trust (until abused) and of decency (the values of fairness, generosity and tolerance). Incentives appropriate to the school's particular students and teachers should be emphasized. ***Parents should be key collaborators and vital members of the school community.***

8. ***The principal and teachers should perceive themselves as generalists first (teachers and scholars in general education)*** and specialists second (experts in but one particular discipline). Staff should expect multiple obligations (teacher-counselor-manager) and a sense of commitment to the entire school.

9. ***Ultimate administrative and budget targets should include, in addition to total student loads per teacher of 80 or fewer pupils on the high school and middle school levels and 20 or fewer on the elementary level, substantial time for collective planning by teachers, competitive salaries for staff, and an ultimate per pupil cost not to exceed that at traditional schools by more than 10 percent***. To accomplish this, administrative plans may have to show the phased reduction or elimination of some services now provided students in many traditional schools.

10. The school should demonstrate non-discriminatory and inclusive policies, practices, and pedagogies. ***It should model democratic practices that involve all who are directly affected by the school.*** The school should honor diversity and build on the strength of its communities, deliberately and explicitly challenging all forms of inequity. (My *italics*.)

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